NAL PROPOSAL No. 0095

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PROPOSAL FOR EXAMINATION OF WIDE ANGLE GAMMA RAYS AT NAL

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ABSTRACT

We wish to propose a simple experiment to examine the energy spectrum of wide angle gamma rays produced in 100 - 500 GeV interactions. Phase I of the experiment will involve a simple measurement of this energy spectrum and phase II will entail observation of the energy spectra for coincident wide angle gammas. Phase I and Phase II will run concurrently.

As a survey experiment which can be done quickly at machine turn on time, we propose to measure the singles and doubles gamma ray energy spectrum emitted in proton-nucleon collisions in the 100 - 500 GeV range. The motivation for each measurement is slightly different and will be treated separately.

Phase I - Single spectrum motivation

Initially we would like to measure the energy spectrum of γ rays at a set of 8 angles in the lab at 20^{o} intervals from approximately 10^{o}

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to 170° with respect to the incident beam direction. We propose to use a lead-lucite sandwich shower counter to measure the energy of the gamma rays. We should be able to attain an average 15% energy resolution in a range extending from .5 to 8 GeV. The approximate angular resolution for a 20 cm. x 20 cm. sensitive area will be approximately 10° at 1 meter from the target.

In this study of the gamma energy spectrum we plan to check the transverse momentum distributions of the detected gammas from the decay of π^0-s originating in the fragmentation of the target nucleon against the predictions of the various models of high energy interactions such as the limiting fragmentation, multipheripheral fireball and thermodynamical models.[1-5] In general each of these models predicts low transverse momentum. Since no gammas with high transverse momentum are expected it would introduce important modifications of present pictures of high energy interactions if such exotic gammas were present. The possibility of seeing effects due to pionization at this forward angle is also present. The opening angle of projectile fragments is on the average very small and does not confuse the picture.

<u>Phase II - Coincidence spectrum motivation</u>

The motivation for observing the gamma coincidences stems from the expectation that the processes[6] which give rise to massive lepton pairs should also give rise to very massive gamma pairs. The experiment[7] of Lederman at BNL has already observed such a spectrum of massive lepton pairs. According to the parton annihilation model of Paschos[8] the cross sections for dimuon and digamma formation should be related by

$$\left(\frac{d\sigma}{dm^2}\right)_{\gamma\gamma} = \left(\frac{d\sigma}{dm^2}\right)_{\mu\mu} \cdot \frac{3}{2}\left(\log\frac{S}{M^2} - 1\right)\frac{\langle Q_i^2\ \bar{Q}_j^2\rangle}{\langle Q_1\ \bar{Q}_j\rangle}$$

where m is the mass of pair, S is the square of total center of mass energy, M is the nucleon mass, and $\frac{\langle Q_i^2 \bar{Q}_j^2 \rangle}{\langle Q_i \bar{Q}_j \rangle}$ is a correlation function of the charge of the parton and antiparton which is equal to 1 if the charge of the parton is 1. In the most optimistic case

$$\left(\frac{d\sigma}{dm^2}\right)_{\gamma\gamma} \sim 9 \left(\frac{d\sigma}{dm^2}\right)_{\mu\mu} \quad \text{at 500 GeV}$$

This mechanism can produce, as indicated by the large digamma mass range shown in fig. 1, correlated gamma rays with high transverse momentum. We should be able to observe the portion of this digamma spectrum in which the digamma center of mass is slow in the lab.

Procedure

We tentatively plan to position experiment in the 14 ft. by 12 ft. gallery forward of the target box in Area I. The target will consist of a .1 mm. Cu foil. This should give 10^6 events/sec/mb of cross section at beam intensities of 10^{12} protons/pulse. Assuming an average multiplicity of 12 at 500 GeV and an equal charge to neutral prongs, we expect a single counting rate of $\sim 6 \times 10^3$ events/sec/mb due mainly to high multiplicity events.

The coincidence counting rate is at this point largely hypothetical. We can only make a model dependent guess extrapolated from Lederman's preliminary data. We estimate

$$\sigma_{\gamma\gamma} \sim 7 \times 10^{-32} \text{ cm}^2$$

It will be possible to see only a fraction of this cross section due to the probable high momentum in the beam direction of the digamma in the lab. Estimating this fraction to be .1 we arrive at a coincidence counting rate for this process of approximately

1 event/100 sec.

Referring to figure 1 both gamma rays should have energies on the average much above 1 GeV and, therefore, be easily separated from random background.arising from multiparticle final states.

We estimate that a minimum of 100 hours of beam time will allow us to accumulate a useful amount of data. The shower counter will be constructed by Johns Hopkins. We do not anticipate requiring any equipment contribution from NAL.

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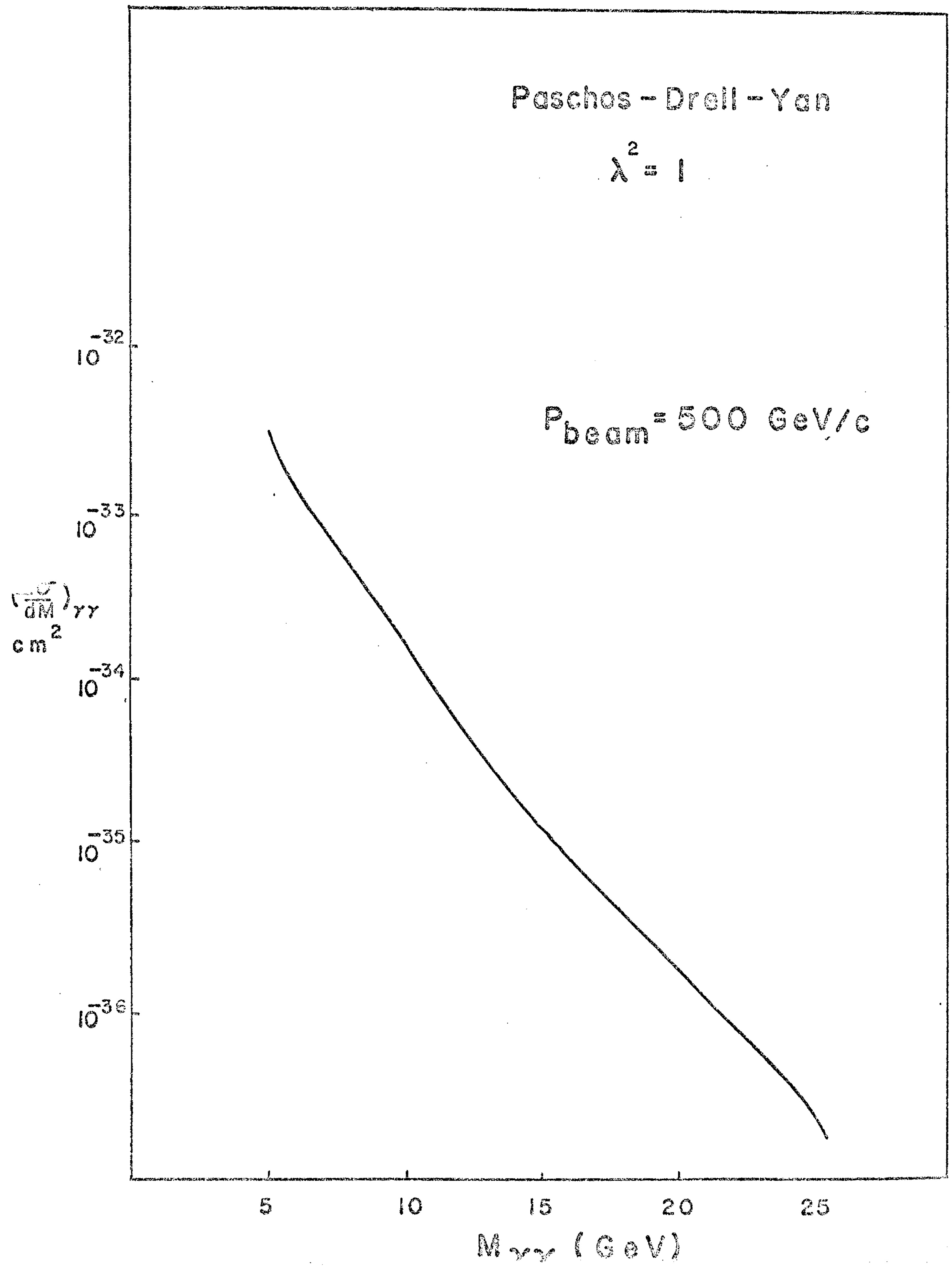

Paschos - Drell - Yan
$\lambda^2 = 1$
$P_{beam} = 500$ GeV/c
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
$\left(\frac{d\sigma}{dM}\right)_{\gamma\gamma}$
cm^2
5
10
15
20
25
$M_{\gamma\gamma}$ (GeV)

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Addendum to Proposal 95

6/18/71

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This addendum amplifies and elaborates on our proposed experiment to examine the gamma ray singles and doubles spectrum arising from pp collisions in the energy range 100 to 500 GeV. We emphasize the experimental procedure and detection technique and the time scale for construction and calibration of suitable Cerenkov detectors.

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In review of our previously submitted proposal we would like to reiterate that we wish to study the gamma ray energy spectrum for single gammas and to search for coincidences between gamma rays emitted in pp collisions. We wish to perform this study at a set of 5 energies between 100 and 500 GeV. Both phases of the proposal will run simultaneously. The PL area of the proton lab constitutes an acceptable location.

Phase I Procedure

The observation of the singles gamma ray energy spectrum will take place simultaneously with the coincidence search. At each energy the gamma ray spectrum will be measured at a set of 17 laboratory angles equally spaced from 10° to 170° with respect to the beam by a lead glass Cerenkov detector placed nominally at 1 meter from the target. Details of the detector are discussed in Appendix I and a schematic of the detector is shown in figure 1. In figure 2 the proposed positioning of the detector for this phase of the experiment is shown. The thin transmission target will consist of a.1 mm Cu. foil. Based on beam size estimates of 1mm in PL the transmission target should have a cross-sectional area of width greater than 1 cm. A preliminary version of a support for the detector which includes the option for both vertical and horizontal positioning and is shown in figure 3. Distances of vertical traverse are based on beam height in PL as outlined in the preliminary construction plans for this area[1].

In order to estimate running times necessary for this phase of the experiment it is necessary to make models of the high energy processes which lead to high pion multiplicities. Based on several theoretical sources[2,3,4] the particle multiplicities in pp collisions should go up approximately as dictated by the general form

$\langle n \rangle \sim a \log S$ Where S is the square of the center of mass energy and $a \sim 2$

This would predict an average multiplicity of a pp collision at 300GeV/c of approximately 8. The statistical I spin independence model[5,6] (which has had some success in predicting the number of π^0's in $\pi^- p$ reactions[7] at 25 GeV) predicts $\langle n \rangle \pi^0 \sim 3$ and an average charged multiplicity of 5 which agrees approximately with the average multiplicity found in the LRL study[8] of pp collisions in the Brookhaven 80" chamber done at 28.5 GeV. The combination of this multiplicity formula and isospin independence further predicts an average charge multiplicity of 6 at 200 GeV in good agreement with the observation of the Michigan group in the Echo Lake cosmic ray data[9]. According to this model these 6 charged tracks should be accompanied by $6\pi^0$. Our model of continuum processes should then incorporate high multiplicities and large numbers of π^0's.

The second salient feature of both the accelerator and cosmic ray data is the low average transverse momentum. It has been pointed out[10] that since low mass fireballs are a feature of cosmic ray data[11] one can obtain such low transverse momentum by assuming that these fireballs arise from peripheral excitation of both the target and projectile and a phase space decay of the excited fireball into a large number of particles.

We have taken this to be a possible model of the multiparticle final states which we propose to observe. It has the added advantage of allowing us to study separately so-called target diffraction and projecticle diffraction merely by ignoring either the slow target fireball or the fast projectile fireball. For definiteness we have assumed in our Monte Carlo studies an average multiplicity of 12 particles with 6 emanating from the target fireball and 6 from the projectile fireball. The momentum transfer dependence assumed is $e^{-.8t}$. For purposes of the rate calculation we estimate $\langle n \rangle_{\pi^0} \sim 6$ and assume that each fireball contains an average of $3\pi^0$.

We show a typical energy spectrum arising from this process in one of the forward detectors in figure 4a at a beam energy of 200 GeV. If we use the pp cross section of 30mb observed in the Echo Lake experiment at 200 GeV as an upper limit for processes of this kind we predict a range of counting rates from 3×10^7 gammas/sec in the 10° position to 3×10^5 gammas/sec in the 170° position. Both numbers are quoted for a distance of 3 meters from the target and 10^{12} protons/pulse. Table 1 summarizes the results for all positions. No cut off has been made on gamma energy. As seen in figure 4 the gamma ray lab energy is peaked relatively low. This is typical of all positions with the energy decreasing with increasing lab angle. This is essentially a reflection of the low transverse momentum of the pions. The high energy gammas are contained in a very tight forward cone a few mrad in aperture and miss the detectors in all positionings. As will be seen in the phase II calculations, processes giving rise to high transverse momentum lead to a very different energy spectrum.

Phase II

In phase II we have proposed to search for coincident gamma ray pairs and examine their mass spectrum. A motivation for such a search includes processes such as very massive neutral bosons decaying into di gamma and the parton annihilation proposed by Paschos[12]. Based on the connection between parton annihilation and the point-like muon pair production observed by Lederman[13] pointed out by the work of Paschos we have constructed a Monte Carlo model of the reaction

$$p + p \to \gamma\gamma + \text{anything}$$

Based on reference 12 we select a di gamma mass which falls as $\frac{1}{m^4_{\gamma\gamma}}$ and is produced in a catastropic collision, recoiling isotropically in the center of mass system against a phase space extending from the nucleon mass upward to the kinematic limit. This sort of model is consistent with the $\mu^+\mu^-$ system observed in the Lederman experiment. Under the assumption of a parton charge of 1, $\sigma_{\gamma\gamma} \sim 8\ \sigma_{\mu^+\mu^-}$ at 200 GeV. Since the cross section for di muon production seems to be rising, we take as a lower limit for $pp \to \mu^+\mu^-$ + anything to be 3×10^{-33} cm^2 (in the forward 65 mrad cone, $p_{\mu^+\mu^-} > 12$ GeV/c, and $M_{\gamma\gamma} > 1$ GeV). We estimate a lower limit of

$$500 \text{ di } \gamma \text{ events/sec} \qquad M_{\gamma\gamma} > 1 \text{ GeV}$$

from Paschos's model and the Lederman data.

The energy spectrum of these events are shown in figure 4b. For comparison with the multiperipheral process in figure 4a we have given expected rates at energies greater than 4000 MeV.

In the coincidence measurement we propose to place two Pb glass detectors in both coplanar and non-coplanar positions. We point out that the non-coplanarity of the parton annihilation model is due only to Fermi energy or the binding of the individual parton in the nucleon. This will serve to enhance the expected coincidence rate for the parton annihilation process when data are taken in a coplanar attitude. However, part of the running time will be devoted to a survey of non-coplanar positioning of the counters to search for other processes such as boson decay which will most certainly not be coplanar with the beam.

We have illustrated in figure 1 one possible positioning of detector 2 in the coincidence search. We have investigated the mass spectrum arising from the multipizero interactions and the parton annihilation model as observed by detector 1 and 2 in several coplanar positionings. We show in figure 5b the spectrum detected in the detector 1 - 20°, detector 2 - 10° coplanar positioning. We estimate for this particular configuration a coincidence counting rate of

$$\text{Multipizero} \sim 10^4/\text{sec at all masses}$$

$$\text{Parton annihilation} \sim 1/3 \text{ sec above 1 GeV}$$

In these calculations we have assumed coplanarity of the parton annihilation process and a 3 meter distance from the target. Finally we estimate the number of multipizero coincidences above 1 GeV to be less than

$$3 \times 10^{-3} \text{ events/sec}$$

Resolution

We have attempted to estimate the mass resolution of this two detector system. Although this is obviously a quantity which depends on the physics being observed we can arrive at an upper limit. Results obtained by the CERN ISR group indicate an attainable energy resolution FWHM of $\frac{\Delta E}{E} \sim 10\%/\sqrt{E}$. We conservatively estimate an energy resolution in this calculation of

$$\frac{\Delta E}{E} \sim 20\%/\sqrt{E}$$

In addition we estimate that through careful examination of the pulse height pattern in our 25 sections of each detector we can localize the shower axis to $\pm$ 2 cm in each direction. Assuming a gaussian distribution with full width of 4 cm and a positioning of detectors 1 and 2 at 1 meter from the target we can achieve a resolution curve shown in figure 6a. In figure 6b we show the mass resolution integrated over all masses. We point out that while these curves obviously depend on the physics observed, we view these as upper limits on the mass resolution. By achieving the better energy resolution and by moving to 3 meters we can improve things greatly.

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Time Schedule

The various stages for the experiment which look feasible now are the following

a) Detector assembly begins	July 1, 1971
b) Detector assembly essentially complete (Based on quoted Pb glass delivery times)	Oct. 1, 1971
c) Detector calibration in electron beam (SLAC or Cornell)	Oct.- Nov. 15, 1971

From this point on we assume that space will be available in the proton area PL from Dec. 15, 1971 and a beam of sorts will be available in Jan. 1972.

d) Equipment assembly at NAL	Dec.15 - Jan. 1, 1972
e) Testing in proton beam	January 1972
f) Duration of setup	1.5 months
g) End of experiment	March, 1972

Manpower

There are available an electrical engineer, an electronics technician, and a programmer who can spend ∿ 50 - 75% of their collective time on various aspects of the experiment. We can count on 1.5 full time graduate students for aid in running and setup. We can commit 3 full time physicists to the execution of the experimental program.

Appendix I

Detectors and Electronics

Each detector, the schematic of which is indicated in figure 1, will consist of 25 rectangular pieces of lead glass of type PEMG4(SF5) or PEMG5(SF1). Each individual subunit will be 5 cm x 5 cm x 25 radiation lengths in size. Using the results of H. Nagel and U. Volkel[14] (see figure 7) on the development of high energy showers we estimate that > 99% of a 6 GeV shower will be contained in the entire detector volume and > 80% will be contained in the subunit initially struck by the photon. (for photons incident on the center of the detector) Each subunit has a separate phototube-base-ADC assembly such that the data taken for each coincidence will consist of 50 pulse heights.

The tentative electronic logic diagram is shown in figure 8. Included is the logic necessary to form the fast coincidence. Table 2 lists the necessary components. Exact coincidence logic will depend on the shower formation in the lead glass, the background of low energy gammas present and the accidental coincidence rate. It may be possible to detect reliably the presence of a shower by simply discriminating on the total light output of the whole detector rather than asking for a very bright subunit. In this case most of the discriminator and or/nor modules listed could be dispensed with. The electronics list has been formulated in terms of EGG modules and a PDP-11 computer but investigation of alternatives is underway.

Calibration of the detectors will be performed in an electron beam either at SLAC or Cornell. This will be as detailed as available running time allows. We would like to calibrate as a function of incident energy and beam position with both detectors in essentially the form desired for the NAL experiment.

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Table 1

Multipizero Production Singles Rate

Angle	Rate
10°	3.0×10^7/sec
20°	3.0×10^7/sec
30°	2.7×10^7/sec
40°	2.2×10^7/sec
50°	1.7×10^7/sec
60°	1.3×10^7/sec
70°	9.7×10^6/sec
80°	7.4×10^6/sec
90°	5.5×10^6/sec
100°	4.3×10^6/sec
110°	3.4×10^6/sec
120°	2.5×10^6/sec
130°	1.8×10^6/sec
140°	1.3×10^6/sec
150°	1.0×10^6/sec
160°	7.0×10^5/sec
170°	3.0×10^5/sec

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Table 2

Electronics*

Item	Description	Model (all EGG)	Quantity+
1	Linear Gate and Stretcher	LG105/N	26 (50)
2	Analog to Digital Converter	AD128E/N	26 (50)
3	Dual updating and discriminator Module	TR204A/N	19 (27)
4	Dual OR/NOR Module	OR102/N	8 (18)
5	Four Fold And/Nand Module	C104A/N	1
6	Dual Four Fold Fanout	F108N	1
7	Strobed Coincidence	C146/N	5 (9)
8	Dual Gate Generator	GG202/N	2
9	Delay Boxes	SAC 032	1
10	Powered NIM Bins	M120A/N	17 (27)
11	Power Supplies		
12	Power Supply Fanouts		

* Or equivalent CAMAC oriented modules.

+ The exact number of modules will depend on the tests conducted in phase (b) of the time schedule. We will basically decide on the geometry of the outer 16 subunits of each. We quote two numbers. The number not in parentheses is the number of modules needed if outer 16 subunits are combined into 4 pieces. The number in parentheses is the number if each subunit is discrete.

JOHNS HOPKINS HIGH ENERGY PHYSICS GROUP	Memo No.	Page 1	Of 1
SUBJECT GAMMA DETECTOR	NAME Figure 1		
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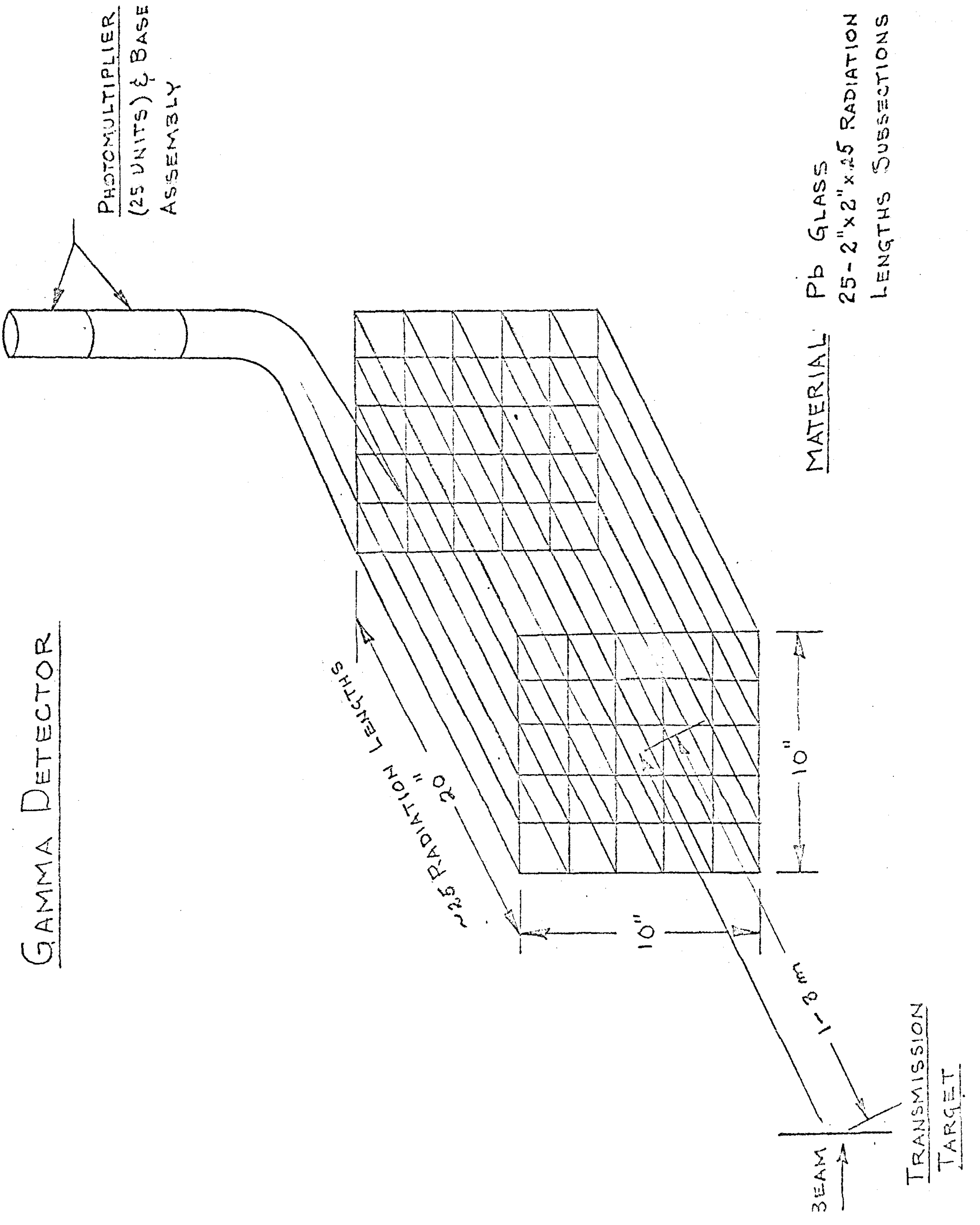
GAMMA DETECTOR



JOHNS HOPKINS HIGH ENERGY PHYSICS GROUP	Memo No.	Page	Of
SUBJECT Detector Positioning	NAME Figure 2		
	DATE		

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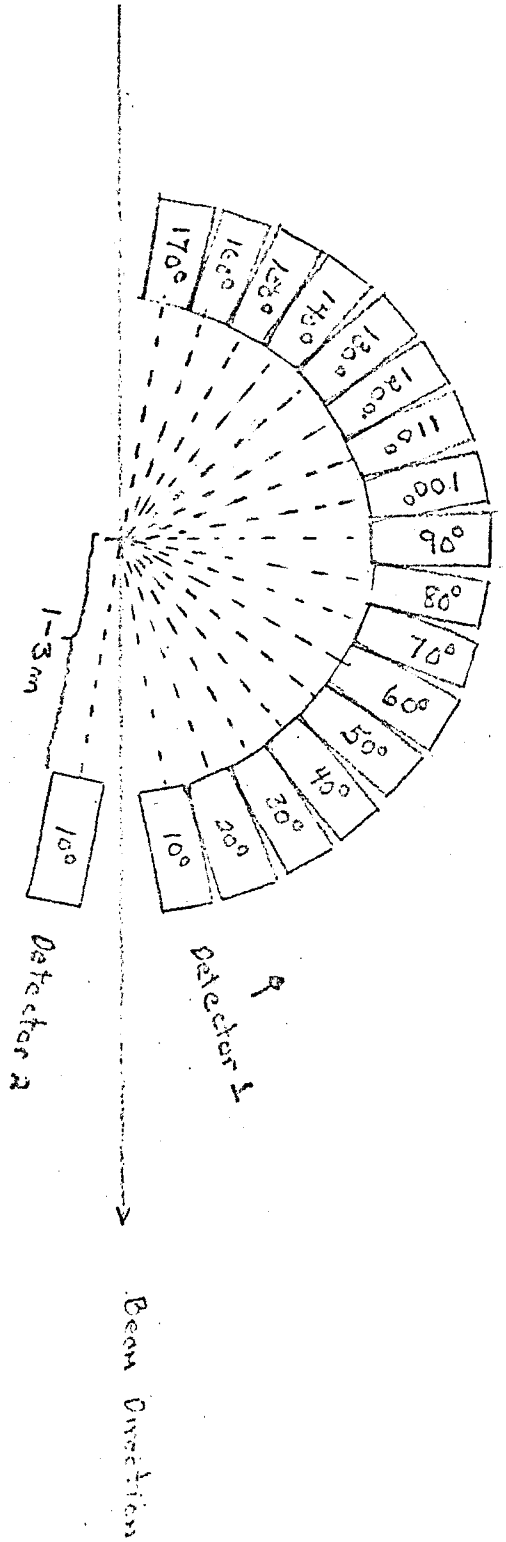
Coplanar Detector Positionings



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SUBJECT Detector Mount	NAME Figure 3		
	DATE		

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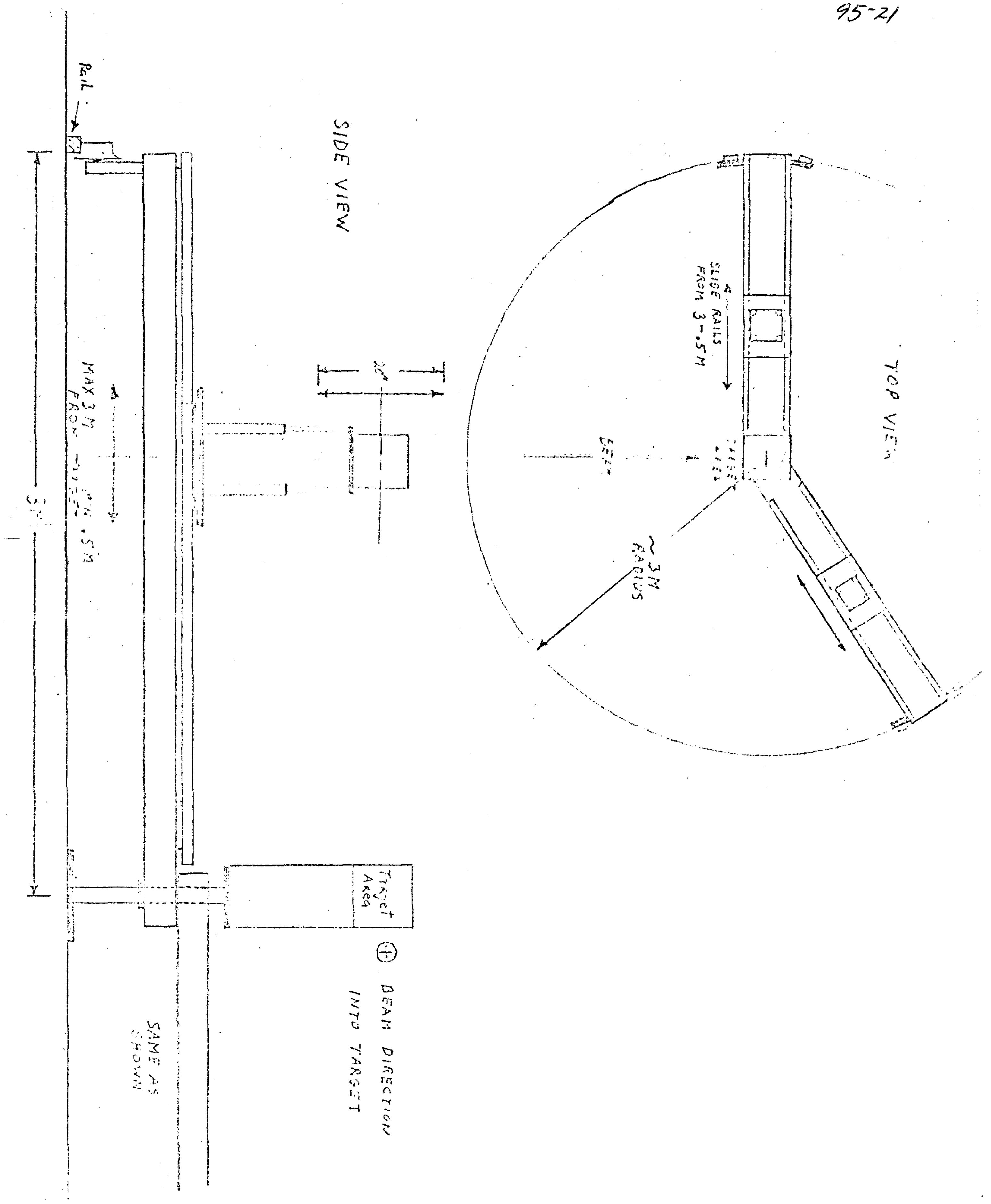

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SUBJECT	NAME Figure 4		
	DATE		

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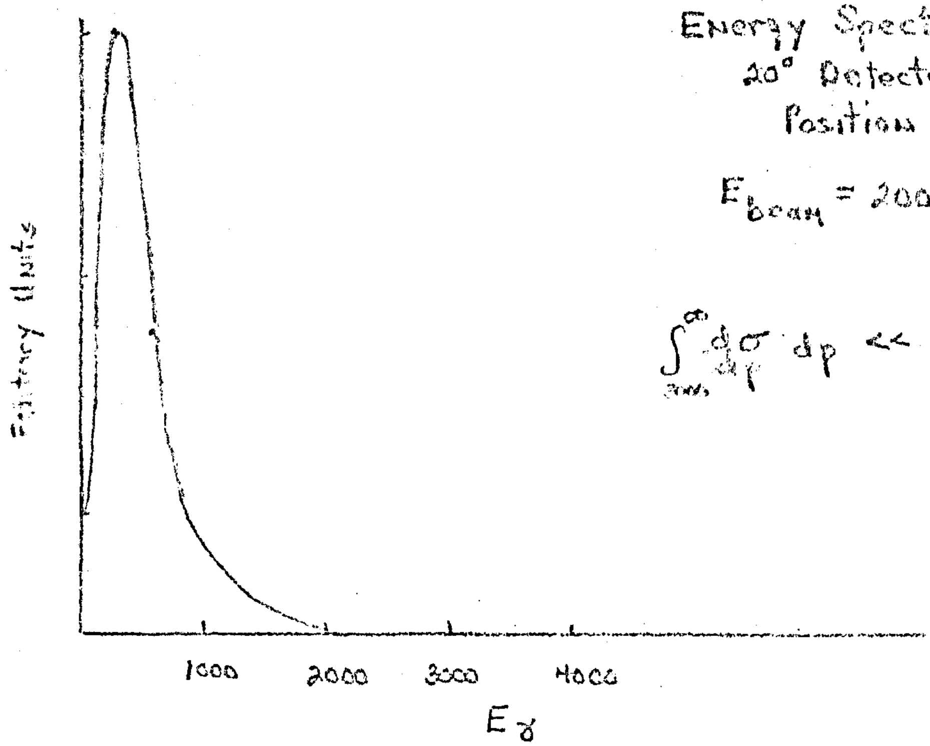
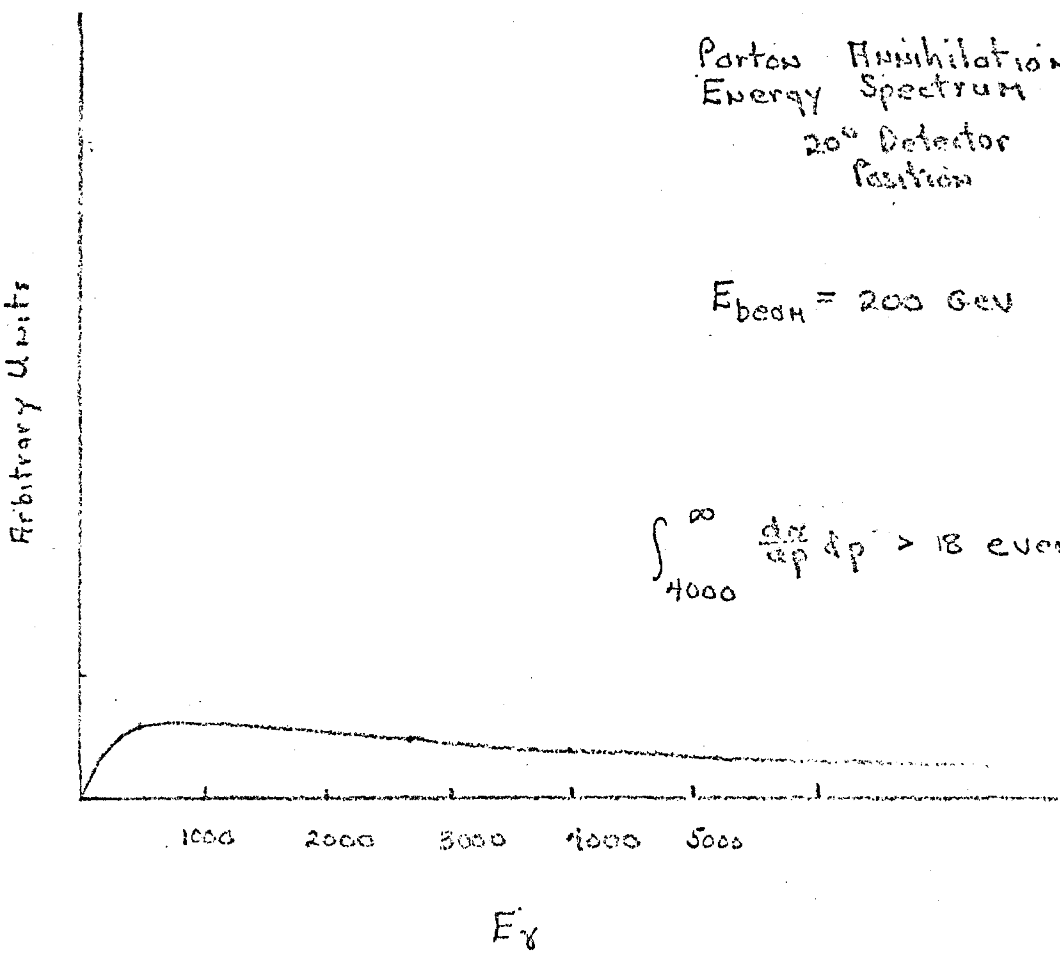


Multi Pi Zero
Energy Spectrum
20° Detector
Position

$E_{beam} = 200$ GeV

$\int_{3000}^{\infty} \frac{d\sigma}{dp}\, dp \ll 10^{-3}$ events/sec



Parton Annihilation
Energy Spectrum
20° Detector
Position

$E_{beam} = 200$ GeV

$\int_{4000}^{\infty} \frac{d\sigma}{dp}\, dp > 18$ events/sec

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SUBJECT	NAME Figure 5		
	DATE		

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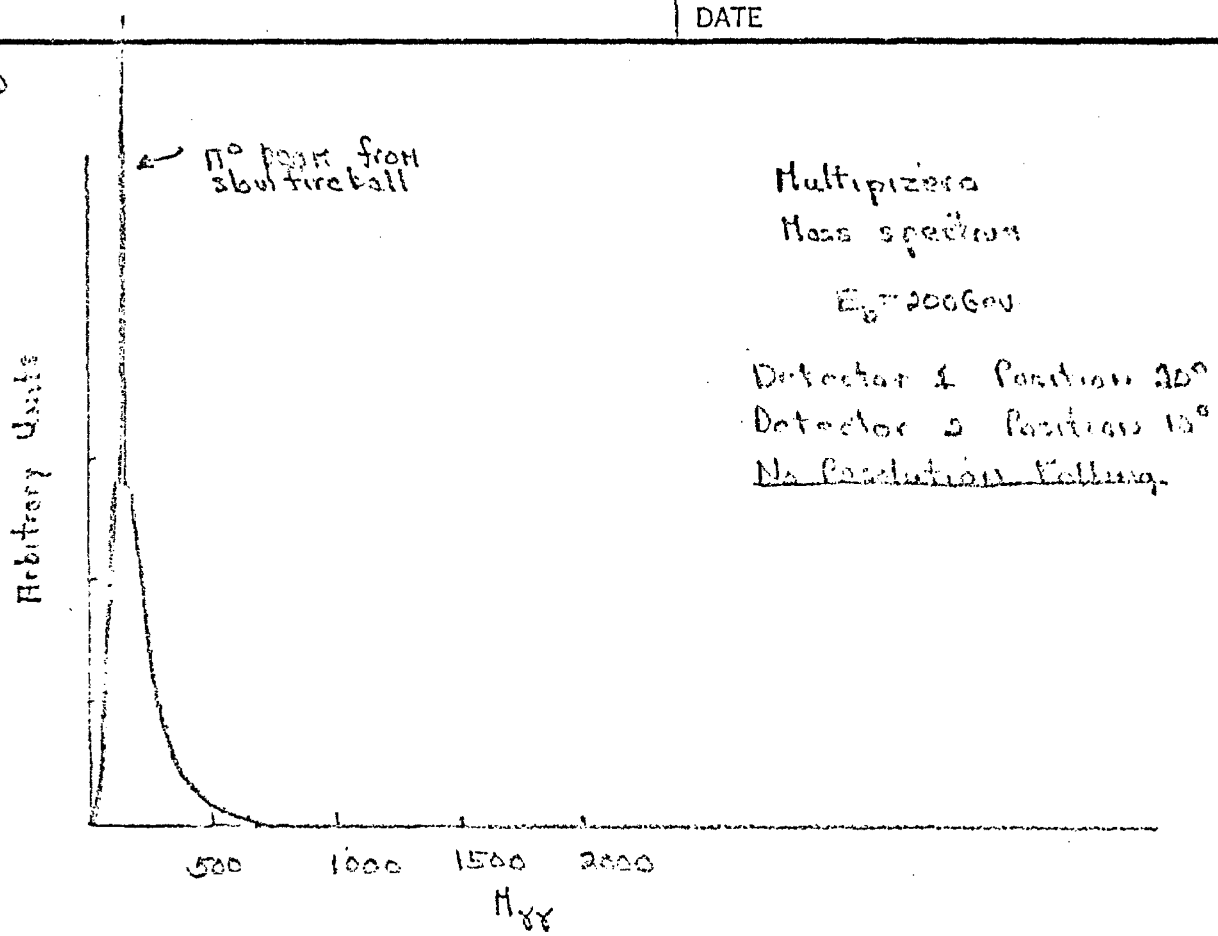
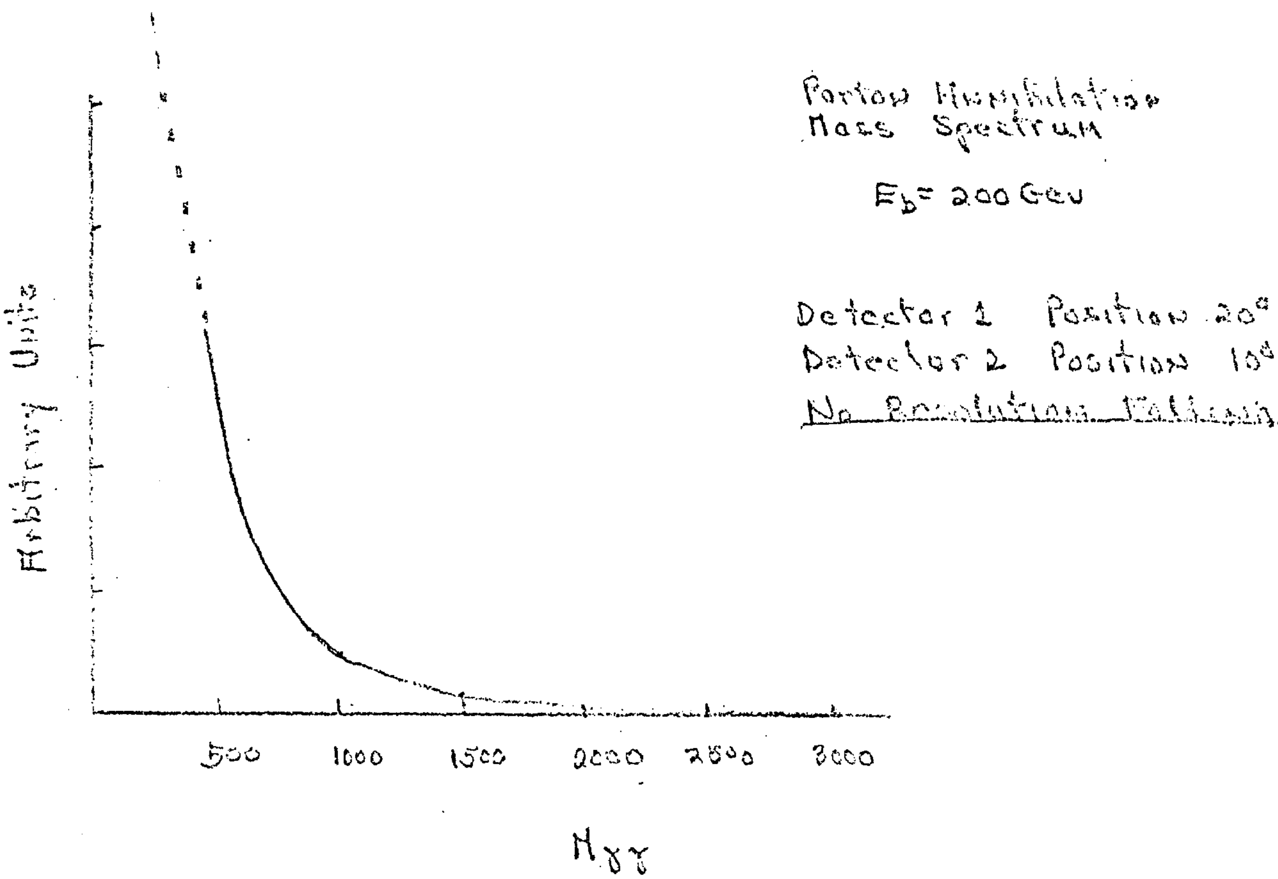
(a)



(b)



JOHNS HOPKINS HIGH ENERGY PHYSICS GROUP	Memo No.	Page	Of
SUBJECT Upper Limit for Mass Resolution Detector 1 -20°, Detector 2 - 10°	NAME Figure [illegible] DATE		

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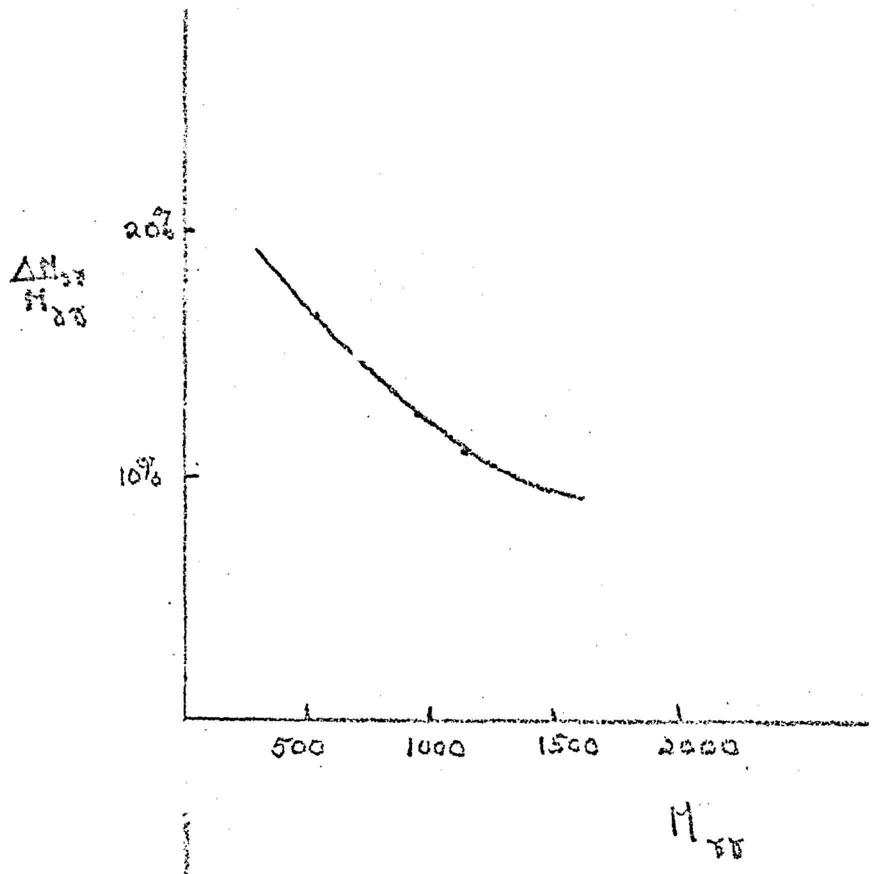
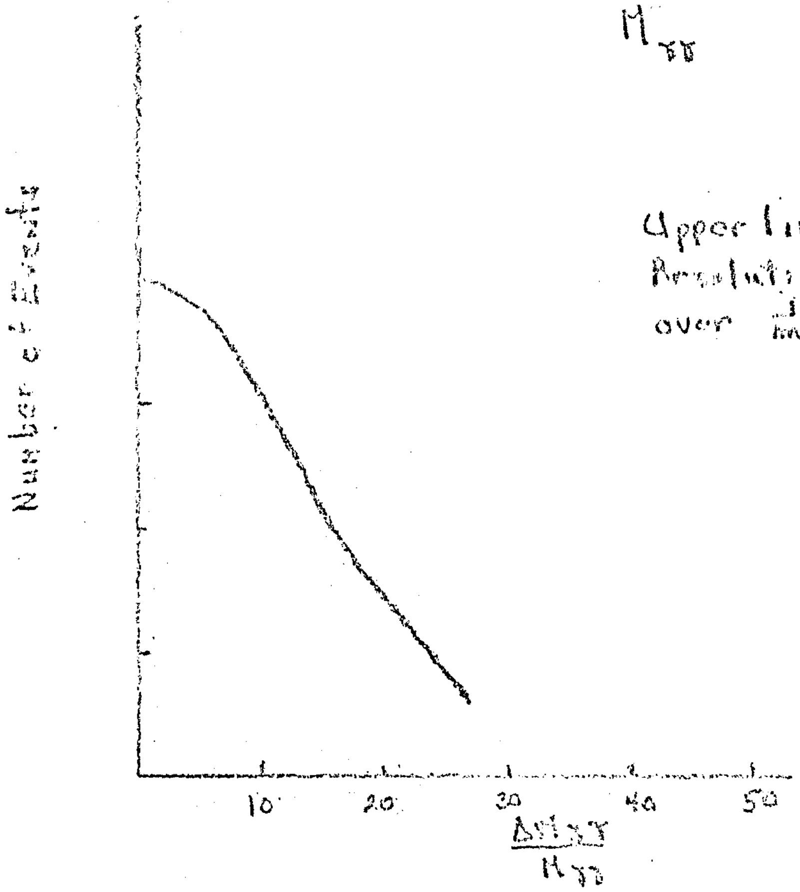
Detector 2 — 10°
Detector 1 - 20°



Upper limit of Mass Resolution integrated over $\frac{1}{M^4}$ mass spectrum



JOHNS HOPKINS HIGH ENERGY PHYSICS GROUP	Memo No.	Page	Of
SUBJECT Shower Development	NAME Figure 7 DATE		

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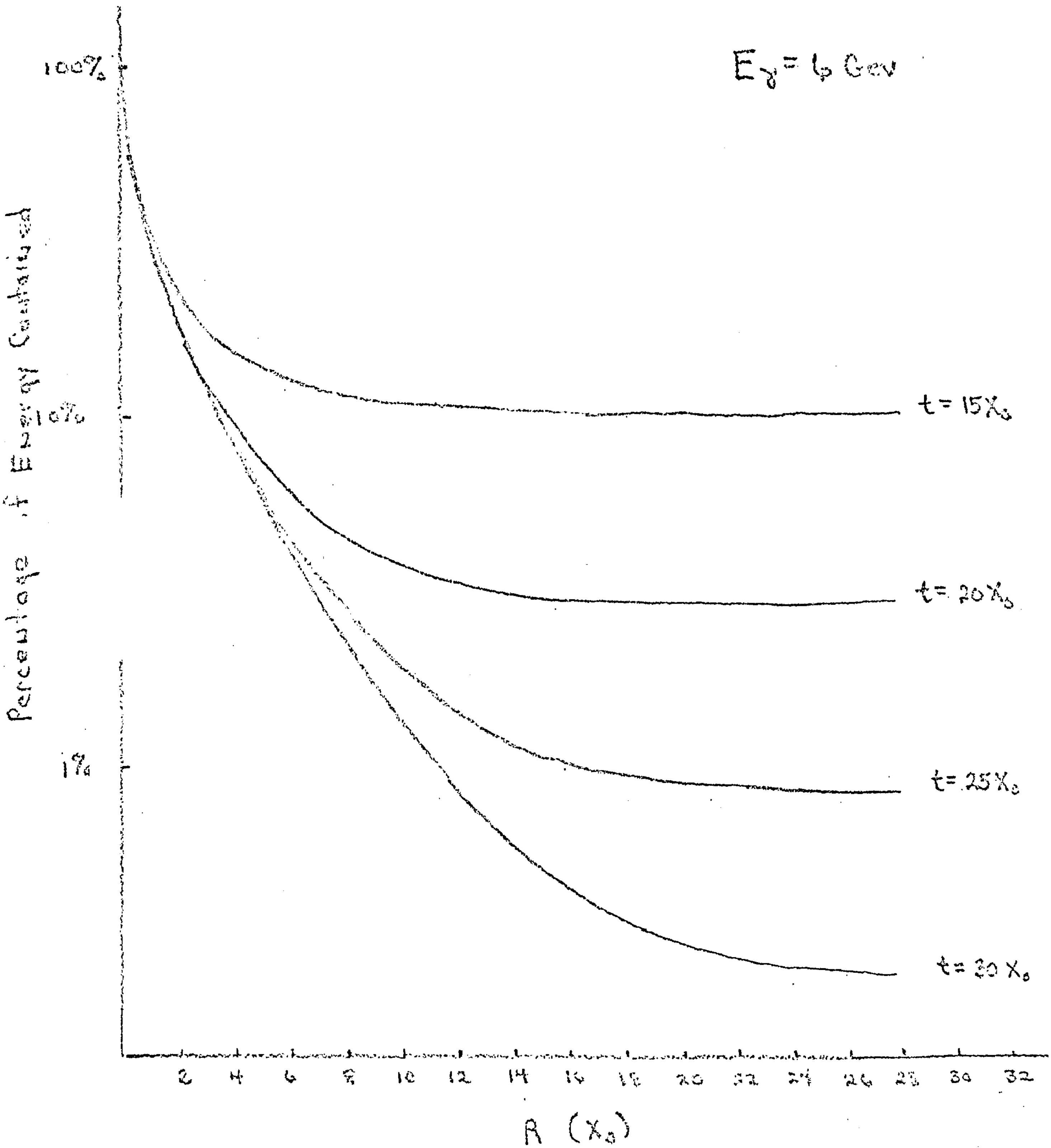

R = radius of cylinder whose axis is shower axis
t = depth of cylinder
X_0 = radiation length

JOHNS HOPKINS HIGH ENERGY PHYSICS GROUP	Memo No.	Page	Of
SUBJECT Electronic Logic Schematic	NAME Figure 8		
	DATE		

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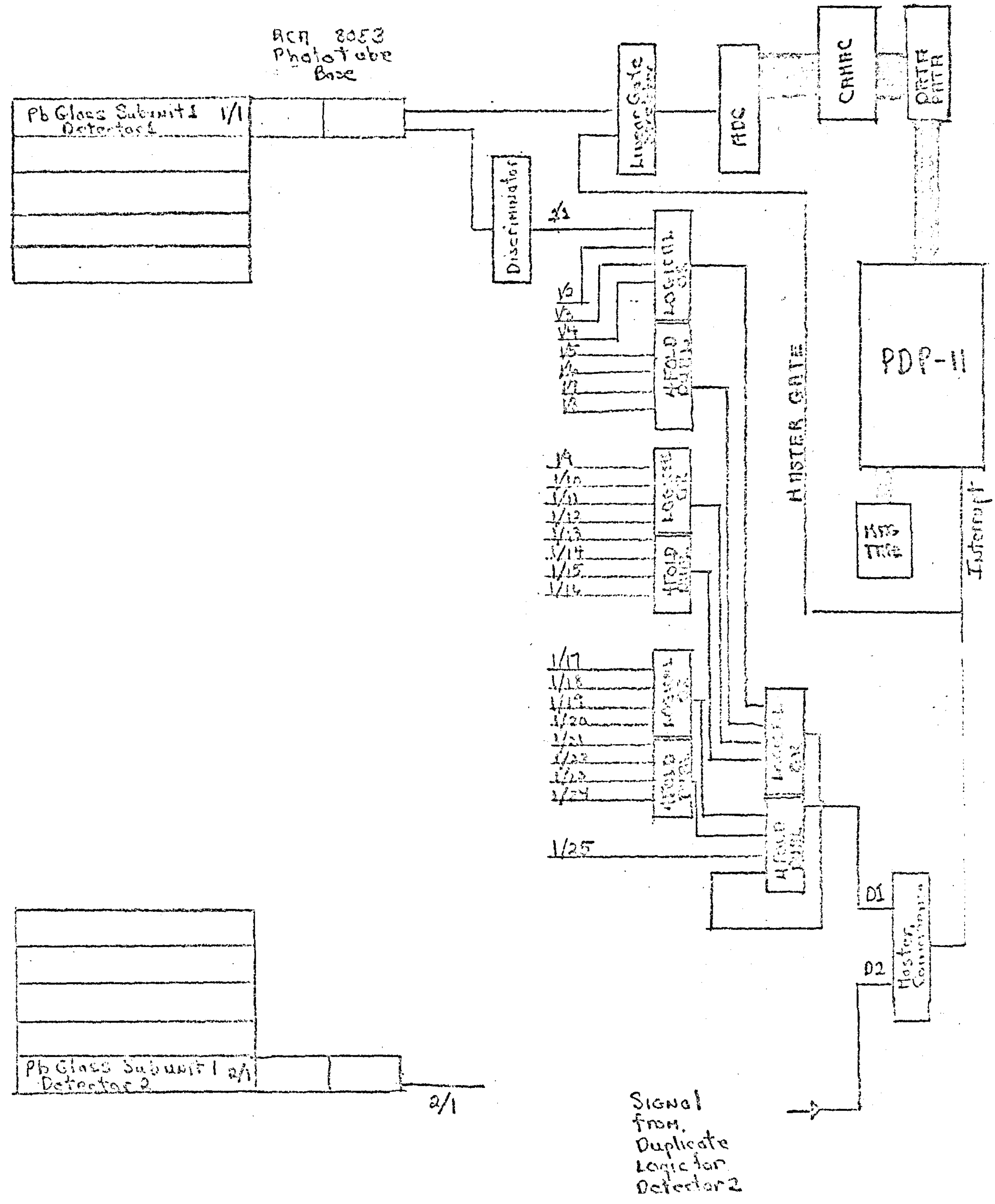
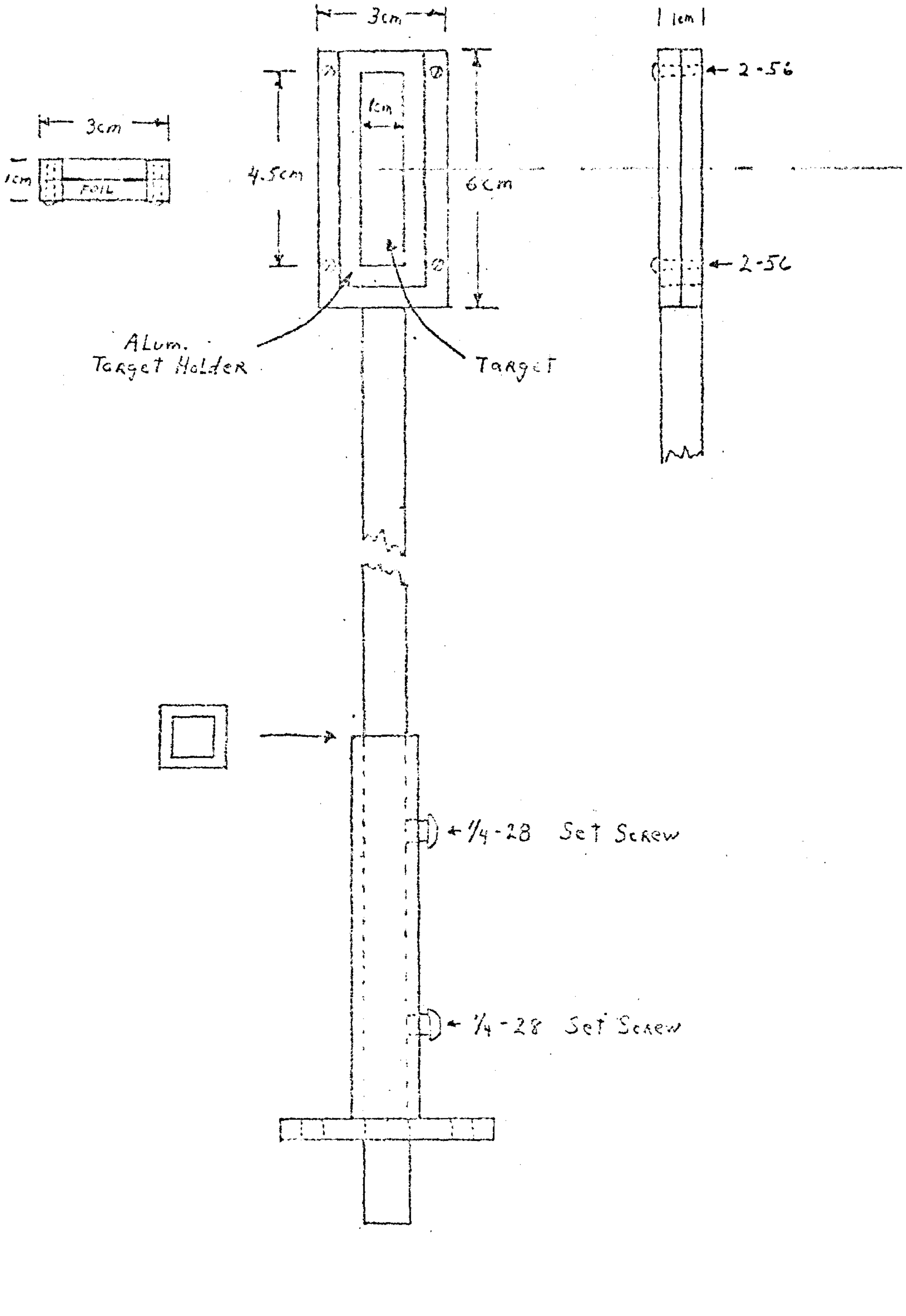


JOHNS HOPKINS HIGH ENERGY PHYSICS GROUP	Memo No.	Page	Of
SUBJECT Target Holder	NAME Figure 9 DATE		

95-27



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Phase I Procedure

The observation of the singles gamma ray energy spectrum will take place simultaneously with the coincidence search. At each energy the gamma ray spectrum will be measured at a set of 17 laboratory angles equally spaced from 10° to 170° with respect to the beam by a lead glass Cerenkov detector placed nominally at 1 meter from the target. Details of the detector are discussed in Appendix I and a schematic of the detector is shown in figure 1. In figure 2 the proposed positioning of the detector for this phase of the experiment is shown. The thin transmission target will consist of a.1 mm Cu. foil. Based on beam size estimates of 1mm in PL the transmission target should have a cross-sectional area of width greater than 1 cm. A preliminary version of a support for the detector which includes the option for both vertical and horizontal positioning and is shown in figure 3. Distances of vertical traverse are based on beam height in PL as outlined in the preliminary construction plans for this area[1].

In order to estimate running times necessary for this phase of the experiment it is necessary to make models of the high energy processes which lead to high pion multiplicities. Based on several theoretical sources[2,3,4] the particle multiplicities in pp collisions should go up approximately as lictated by the general form

$\langle n \rangle \sim a \log S$ — Where S is the square of the center of mass energy and $a \sim 2$

This would predict an average multiplicity of a pp collision at 30 GeV/c of approximately 8. The statistical I spin independence model[5,6] (which has had some success in predicting the number of π^{o}'s in $\pi^{-}p$ reactions[7] at 25 GeV) predicts $\langle n \rangle\ \pi^{o} \sim 3$ and an average charged multiplicity of 5 which agrees approximately with the average multiplicity found in the LRL study[8] of pp collisions in the Brookhaven 80" chamber done at 28.5 GeV. The combination of this multiplicity formula and isospin independence further predicts an average charge multiplicity of 6 at 200 GeV in good agreement with the observation of the Michigan group in the Echo Lake cosmic ray data[9]. According to this model these 6 charged tracks should be accompanied by $6\pi^{o}$. Our model of continuum processes should then incorporate high multiplicities and large numbers of π^{o}'s.

The second salient feature of both the accelerator and cosmic ray data is the low average transverse momentum. It has been pointed out[10] that since low mass fireballs are a feature of cosmic ray data[11] one can obtain such low transverse momentum by assuming that these fireballs arise from peripheral excitation of both the target and projectile and a phase space decay of the excited fireball into a large number of particles.

We have taken this to be a possible model of the multiparticle final states which we propose to observe. It has the added advantage of allowing us to study separately so-called target diffraction and projecticle diffraction merely by ignoring either the slow target fireball or the fast projectile fireball. For definiteness we have assumed in our Monte Carlo studies an average multiplicity of 12 particles with 6 emanating from the target fireball and 6 from the projectile fireball. The momentum transfer dependence assumed is $e^{-.8t}$. For purposes of the rate calculation we estimate $\langle n \rangle_{\pi^0} \sim 6$ and assume that each fireball contains an average of $3\pi^0$.

We show a typical energy spectrum arising from this process in one of the forward detectors in figure 4a at a beam energy of 200 GeV. If we use the pp cross section of 30mb observed in the Echo Lake experiment at 200 GeV as an upper limit for processes of this kind we predict a range of counting rates from 3×10^7 gammas/sec in the 10° position to 3×10^5 gammas/sec in the 170° position. Both numbers are quoted for a distance of 3 meters from the target and 10^{12} protons/pulse. Table 1 summarizes the results for all positions. <u>No cut off has been made on gamma energy</u>. As seen in figure 4 the gamma ray lab energy is peaked relatively low. This is typical of all positions with the energy decreasing with increasing lab angle. This is essentially a reflection of the low transverse momentum of the pions. The high energy gammas are contained in a very tight forward cone a few mrad in aperture and miss the detectors in all positionings. As will be seen in the phase II calculations, processes giving rise to high transverse momentum lead to a very different energy spectrum.

<u>Phase II</u>

In phase II we have proposed to search for coincident gamma ray pairs and examine their mass spectrum. A motivation for such a search includes processes such as very massive neutral bosons decaying into di gamma and the parton annihilation proposed by Paschos[12]. Based on the connection between parton annihilation and the point-like muon pair production observed by Lederman[13] pointed out by the work of Paschos we have constructed a Monte Carlo model of the reaction

$$p + p \rightarrow \gamma\gamma + \text{anything}$$

Based on reference 12 we select a di gamma mass which falls as $\frac{1}{m^4_{\gamma\gamma}}$ and is produced in a catastropic collision, recoiling isotropically in the center of mass system against a phase space extending from the nucleon mass upward to the kinematic limit. This sort of model is consistent with the $\mu^+\mu^-$ system observed in the Lederman experiment. Under the assumption of a parton charge of 1, $\sigma_{\gamma\gamma} \sim 8\, \sigma_{\mu^+\mu^-}$ at 200 GeV. Since the cross section for di muon production seems to be rising, we take as a lower limit for $pp \to \mu^+\mu^- +$ anything to be 3×10^{-33} cm^2 (in the forward 65 mrad cone, $p_{\mu^+\mu^-} > 12$ GeV/c, and $M_{\gamma\gamma} > 1$ GeV). We estimate a lower limit of

$$500 \text{ di } \gamma \text{ events/sec} \qquad M_{\gamma\gamma} > 1 \text{ GeV}$$

from Paschos's model and the Lederman data.

The energy spectrum of these events are shown in figure 4b. For comparison with the multiperipheral process in figure 4a we have given expected rates at energies greater than 4000 MeV.

In the coincidence measurement we propose to place two Pb glass detectors in both coplanar and non-coplanar positions. We point out that the non-coplanarity of the parton annihilation model is due only to Fermi energy or the binding of the individual parton in the nucleon. This will serve to enhance the expected coincidence rate for the parton annihilation process when data are taken in a coplanar attitude. However, part of the running time will be devoted to a survey of non-coplanar positioning of the counters to search for other processes such as boson decay which will most certainly not be coplanar with the beam.

We have illustrated in figure 1 one possible positioning of detector 2 in the coincidence search. We have investigated the mass spectrum arising from the multipizero interactions and the parton annihilation model as observed by detector 1 and 2 in several coplanar positionings. We show in figure 5b the spectrum detected in the detector 1 - 20°, detector 2 - 10° coplanar positioning. We estimate for this particular configuration a coincidence counting rate of

$$\text{Multipizero} \sim 10^4/\text{sec at all masses}$$

$$\text{Parton annihilation} \sim 1/3 \text{ sec above 1 GeV}$$

In these calculations we have assumed coplanarity of the parton annihilation process and a 3 meter distance from the target. Finally we estimate the number of multipizero coincidences above 1 GeV to be less than

$$3 \times 10^{-3} \text{ events/sec}$$

Resolution

We have attempted to estimate the mass resolution of this two detector system. Although this is obviously a quantity which depends on the physics being observed we can arrive at an upper limit. Results obtained by the CERN ISR group indicate an attainable energy resolution FWHM of $\frac{\Delta E}{E} \sim 10\%/\sqrt{E}$. We conservatively estimate an energy resolution in this calculation of

$$\frac{\Delta E}{E} \sim 20\%/\sqrt{E}$$

In addition we estimate that through careful examination of the pulse height pattern in our 25 sections of each detector we can localize the shower axis to $\pm$ 2 cm in each direction. Assuming a gaussian distribution with full width of 4 cm and a positioning of detectors 1 and 2 at 1 meter from the target we can achieve a resolution curve shown in figure 6a. In figure 6b we show the mass resolution integrated over all masses. We point out that while these curves obviously depend on the physics observed, we view these as upper limits on the mass resolution. By achieving the better energy resolution and by moving to 3 meters we can improve things greatly.

Time Schedule

The various stages for the experiment which look feasible now are the following

a) Detector assembly begins	July 1, 1971
b) Detector assembly essentially complete (Based on quoted Pb glass delivery times)	Oct. 1, 1971
c) Detector calibration in electron beam (SLAC or Cornell)	Oct.- Nov. 15, 1971

From this point on we assume that space will be available in the proton area PL from Dec. 15, 1971 and a beam of sorts will be available in Jan. 1972.

d) Equipment assembly at NAL	Dec.15 - Jan. 1, 1972
e) Testing in proton beam	January 1972
f) Duration of setup	1.5 months
g) End of experiment	March, 1972

Manpower

There are available an electrical engineer, an electronics technician, and a programmer who can spend $\sim$ 50 - 75% of their collective time on various aspects of the experiment. We can count on 1.5 full time graduate students for aid in running and setup. We can commit 3 full time physicists to the execution of the experimental program.

Appendix I

Detectors and Electronics

Each detector, the schematic of which is indicated in figure 1, will consist of 25 rectangular pieces of lead glass of type PEMG4(SF5) or PEMG5(SF1). Each individual subunit will be 5 cm x 5 cm x 25 radiation lengths in size. Using the results of H. Nagel and U. Volkel[14] (see figure 7) on the development of high energy showers we estimate that > 99% of a 6 GeV shower will be contained in the entire detector volume and > 80% will be contained in the subunit initially struck by the photon. (for photons incident on the center of the detector) Each subunit has a separate phototube-base-ADC assembly such that the data taken for each coincidence will consist of 50 pulse heights.

The tentative electronic logic diagram is shown in figure 8. Included is the logic necessary to form the fast coincidence. Table 2 lists the necessary components. Exact coincidence logic will depend on the shower formation in the lead glass, the background of low energy gammas present and the accidental coincidence rate. It may be possible to detect reliably the presence of a shower by simply discriminating on the total light output of the whole detector rather than asking for a very bright subunit. In this case most of the discriminator and or/nor modules listed could be dispensed with. The electronics list has been formulated in terms of EGG modules and a PDP-11 computer but investigation of alternatives is underway.

Calibration of the detectors will be performed in an electron beam either at SLAC or Cornell. This will be as detailed as available running time allows. We would like to calibrate as a function of incident energy and beam position with both detectors in essentially the form desired for the NAL experiment.

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Table 1

Multipizero Production Singles Rate

Angle	Rate
10°	3.0×10^7/sec
20°	3.0×10^7/sec
30°	2.7×10^7/sec
40°	2.2×10^7/sec
50°	1.7×10^7/sec
60°	1.3×10^7/sec
70°	9.7×10^6/sec
80°	7.4×10^6/sec
90°	5.5×10^6/sec
100°	4.3×10^6/sec
110°	3.4×10^6/sec
120°	2.5×10^6/sec
130°	1.8×10^6/sec
140°	1.3×10^6/sec
150°	1.0×10^6/sec
160°	7.0×10^5/sec
170°	3.0×10^5/sec

Table 2

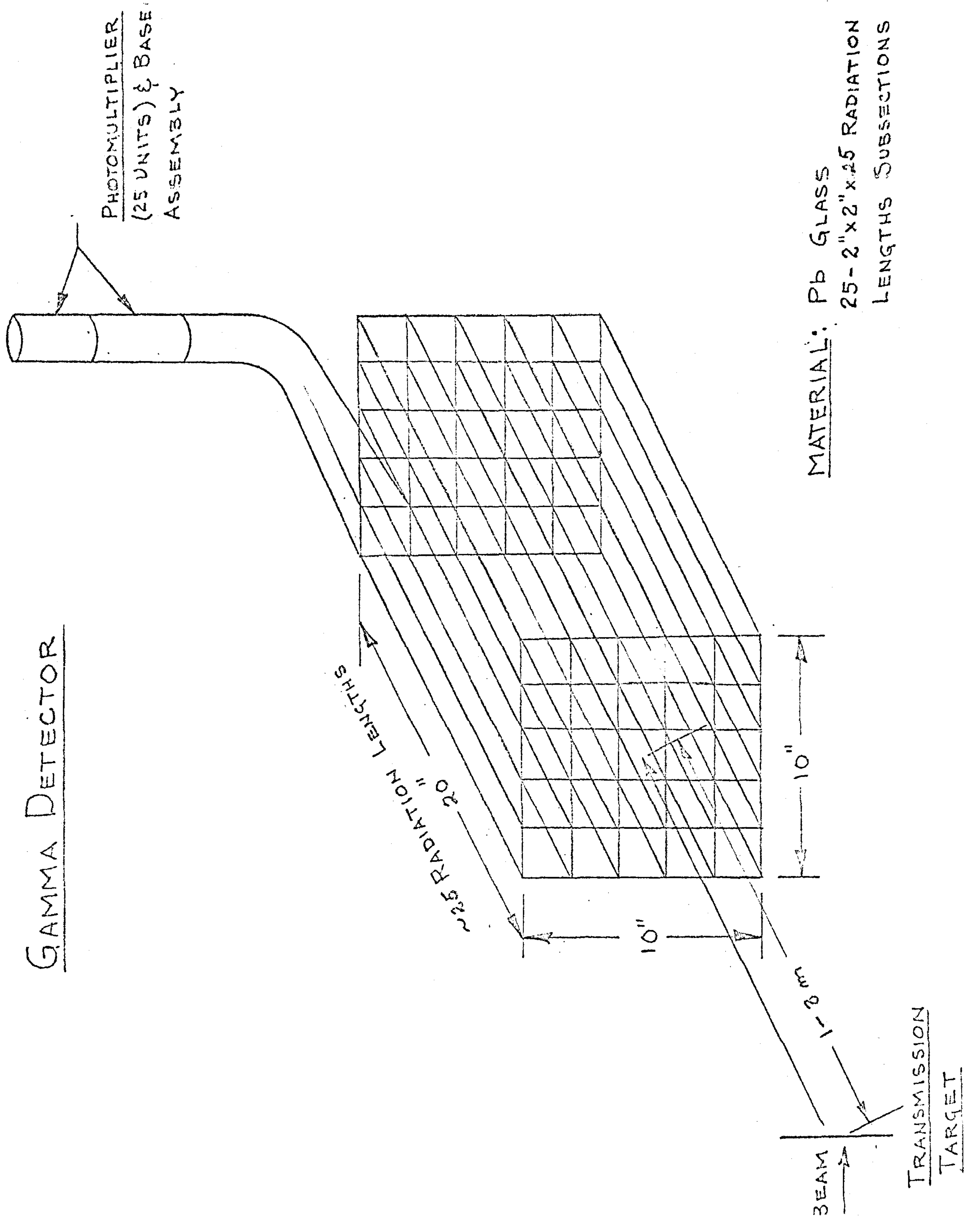
Electronics*

Item	Description	Model (all EGG)	Quantity+	
1	Linear Gate and Stretcher	LG105/N	26	(50)
2	Analog to Digital Converter	AD128E/N	26	(50)
3	Dual updating and discriminator Module	TR204A/N	19	(27)
4	Dual OR/NOR Module	OR102/N	8	(18)
5	Four Fold And/Nand Module	C104A/N	1	
6	Dual Four Fold Fanout	F108N	1	
7	Strobed Coincidence	C146/N	5	(9)
8	Dual Gate Generator	GG202/N	2	
9	Delay Boxes	SAC 032	1	
10	Powered NIM Bins	M120A/N	17	(27)
11	Power Supplies			
12	Power Supply Fanouts			

* Or equivalent CAMAC oriented modules.

+ The exact number of modules will depend on the tests conducted in phase (b) of the time schedule. We will basically decide on the geometry of the outer 16 subunits of each. We quote two numbers. The number not in parentheses is the number of modules needed if outer 16 subunits are combined into 4 pieces. The number in parentheses is the number if each subunit is discrete.

JOHNS HOPKINS HIGH ENERGY PHYSICS GROUP	Memo No.	Page 1	Of 1
SUBJECT GAMMA DETECTOR	NAME Figure 1		
	DATE 4/29/71		R.D.CAW



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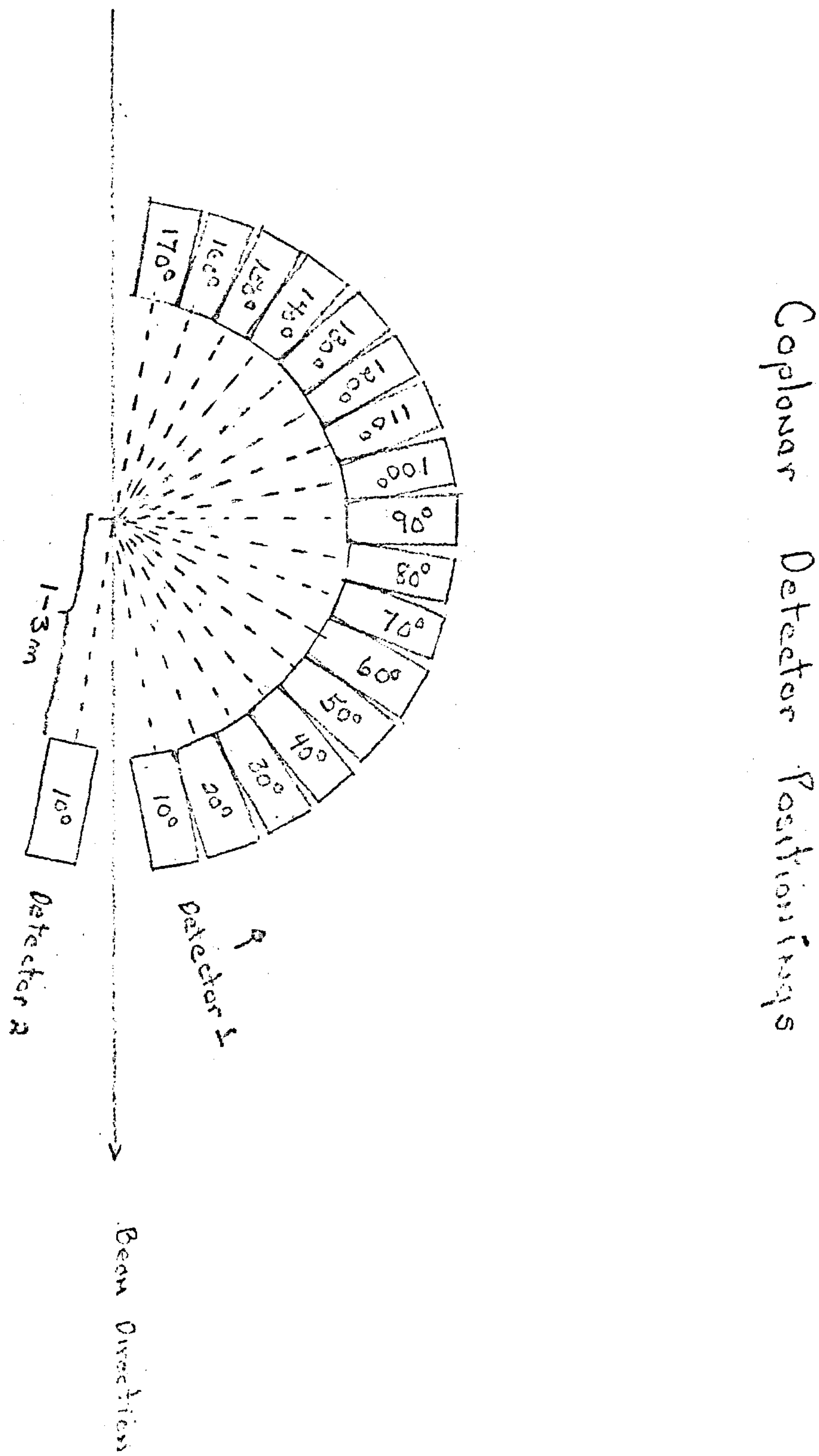
SUBJECT Detector Positioning	NAME Figure 2 DATE		



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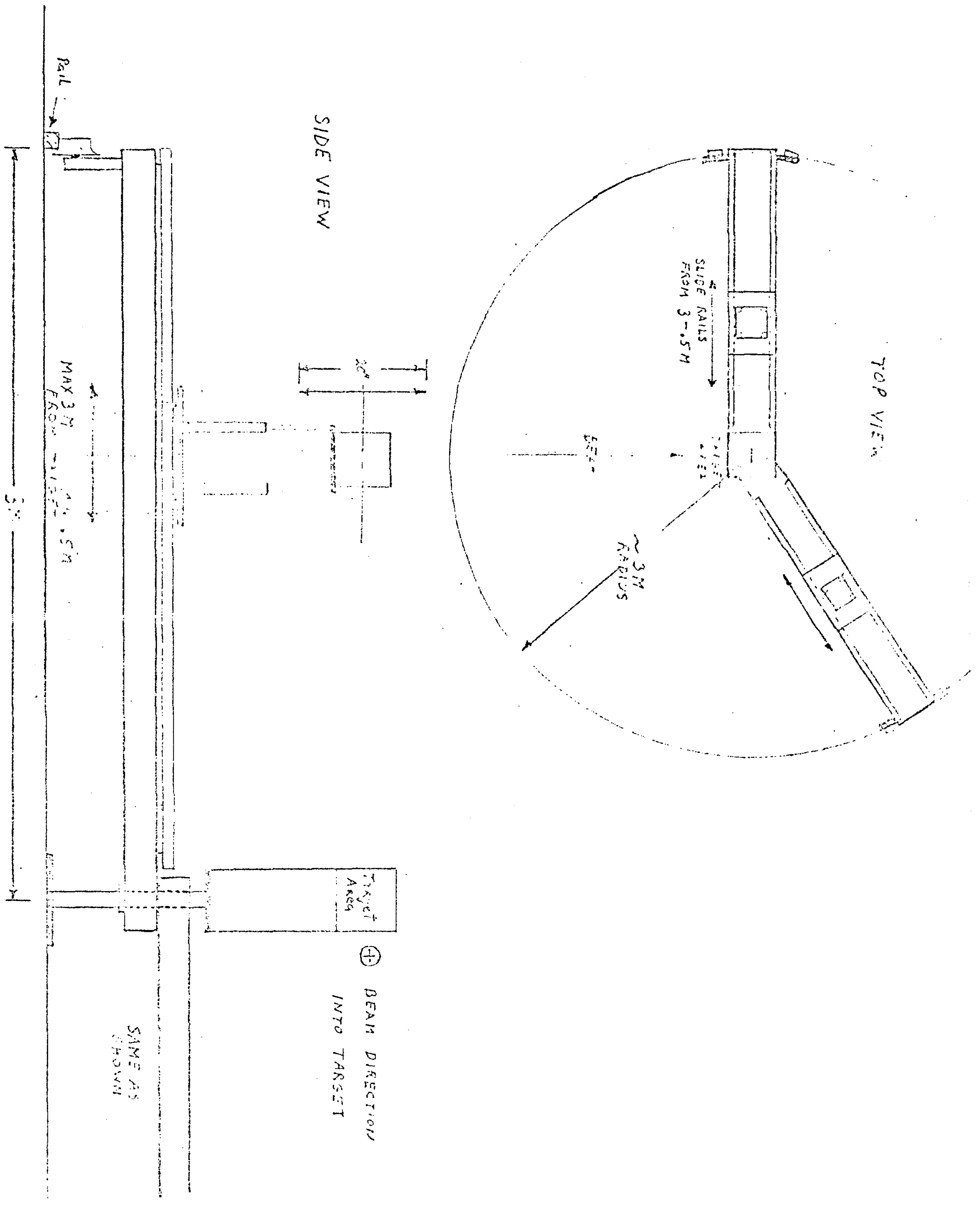
SUBJECT Detector Mount	NAME Figure 3		
	DATE		



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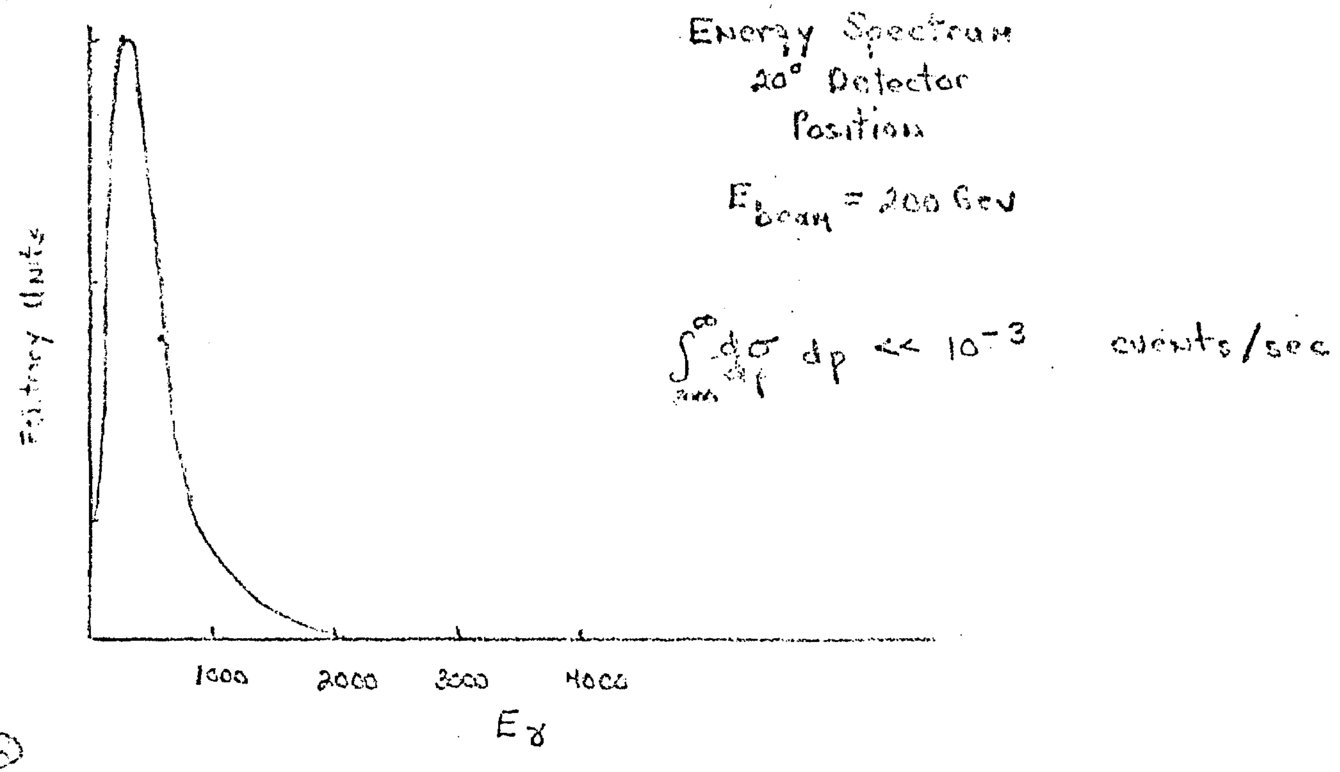
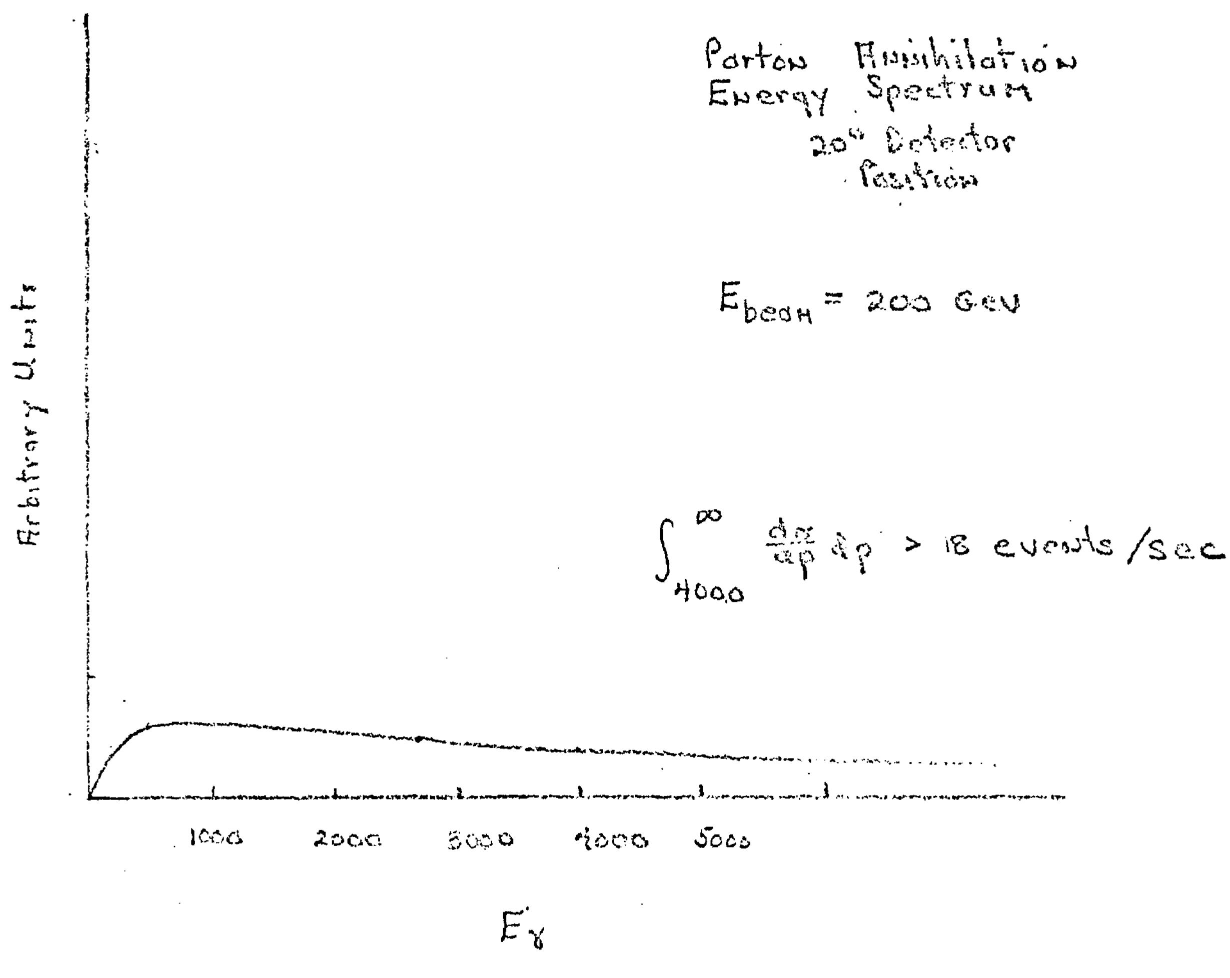
SUBJECT	NAME Figure 4		
	DATE		

(a)



(b)



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SUBJECT	NAME Figure 5		
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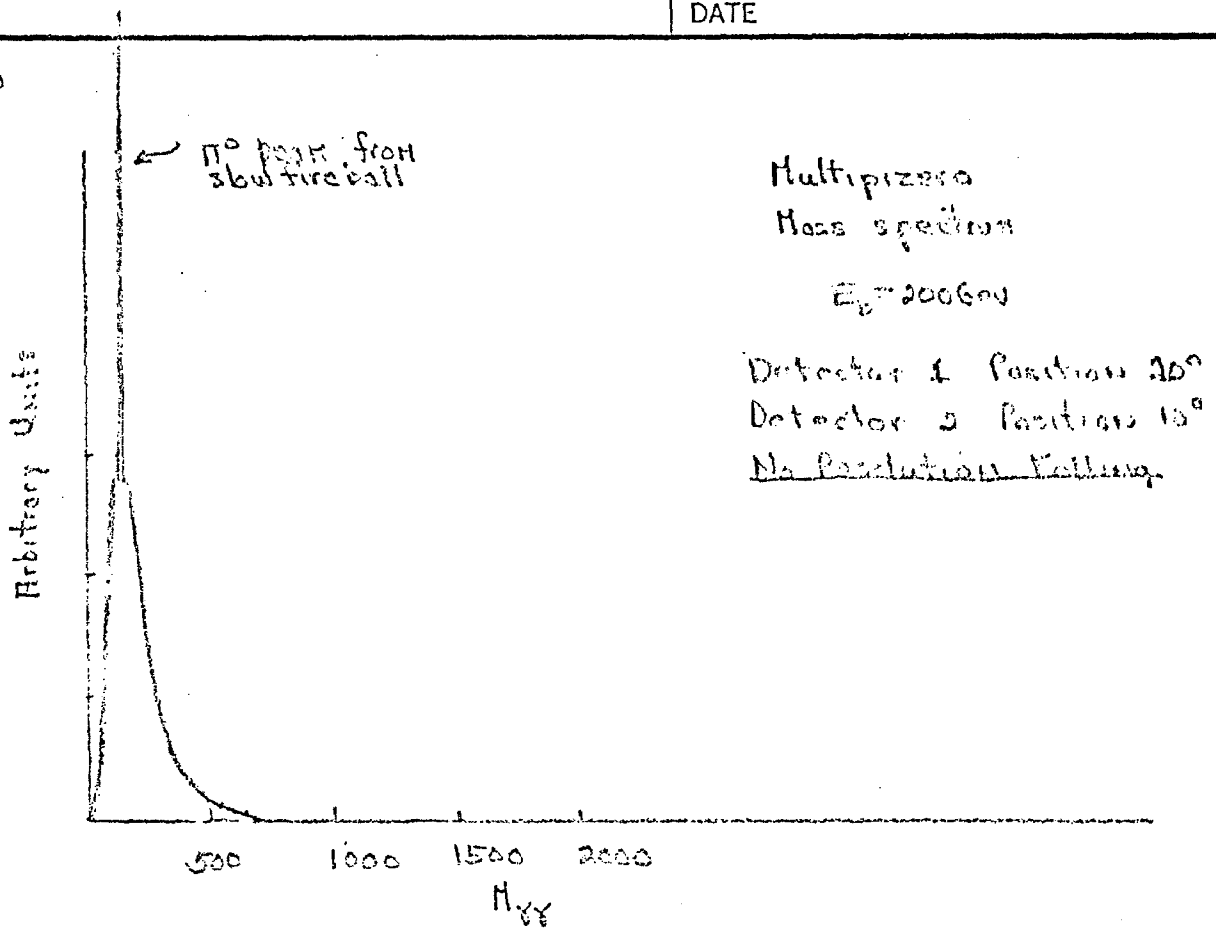

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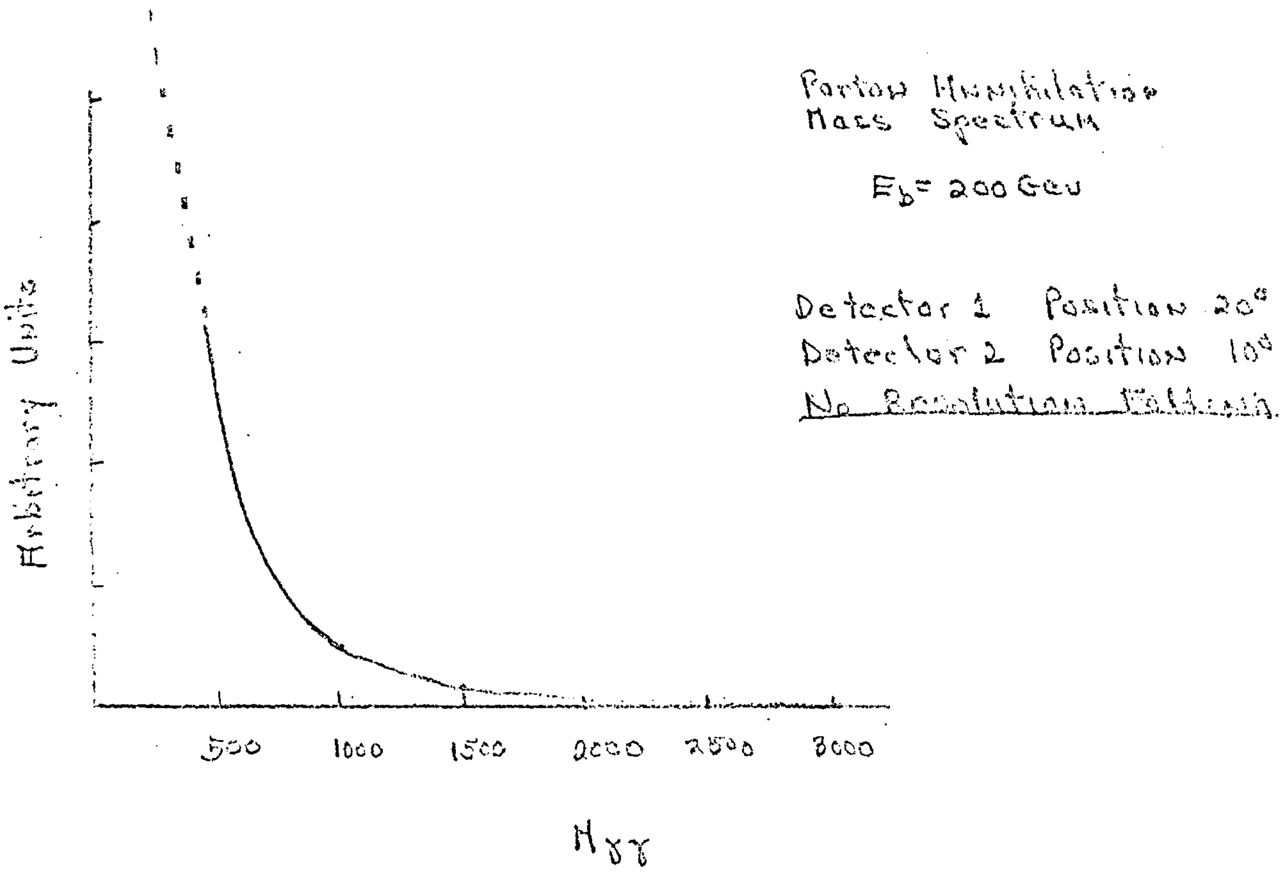
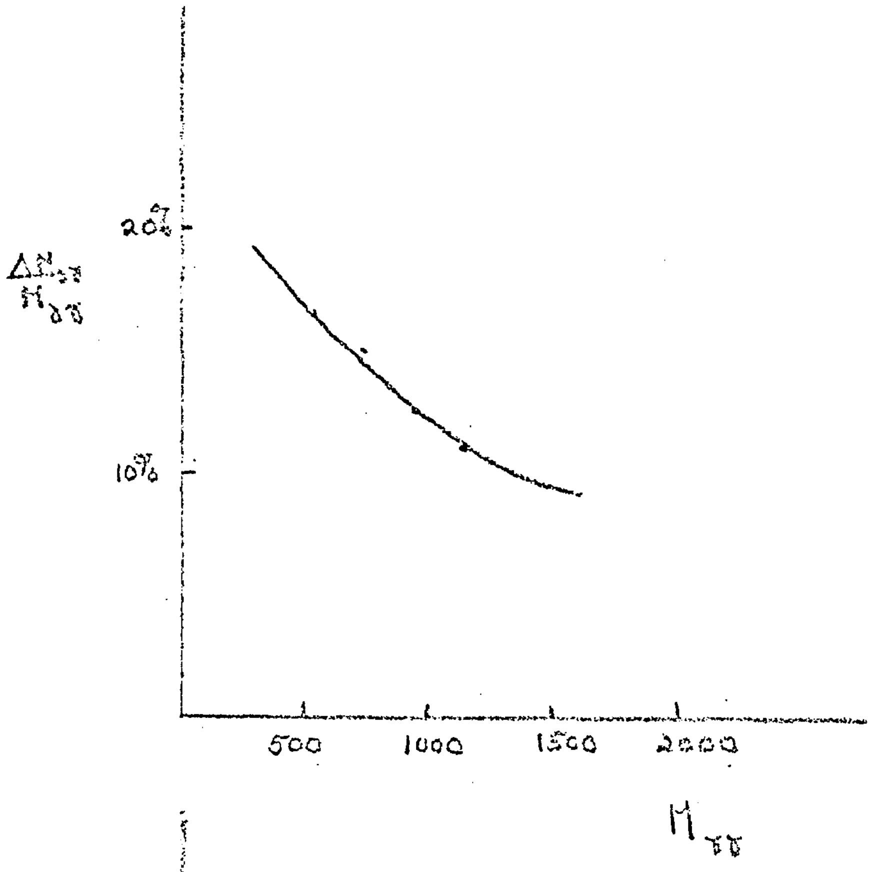
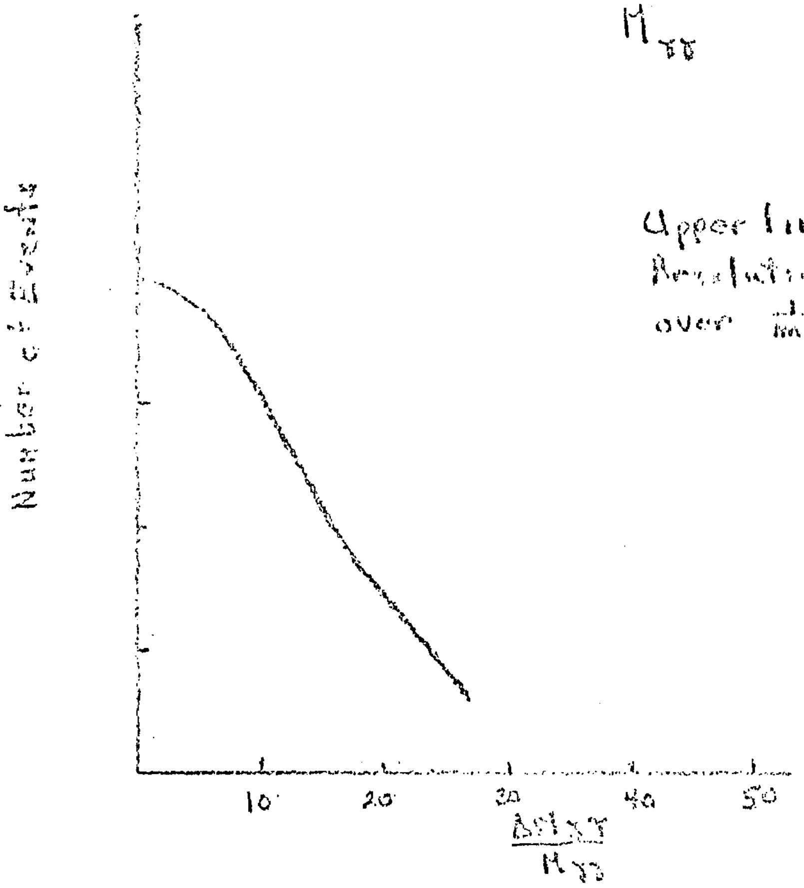


JOHNS HOPKINS HIGH ENERGY PHYSICS GROUP	Memo No.	Page	Of
SUBJECT Upper Limit for Mass Resolution Detector 1 - 20°, Detector 2 - 10°	NAME Figure 6		
	DATE		

Detector 2 - 10°
Detector 1 - 20°





Upper limit of Mass Resolutions integrated over total mass spectrum

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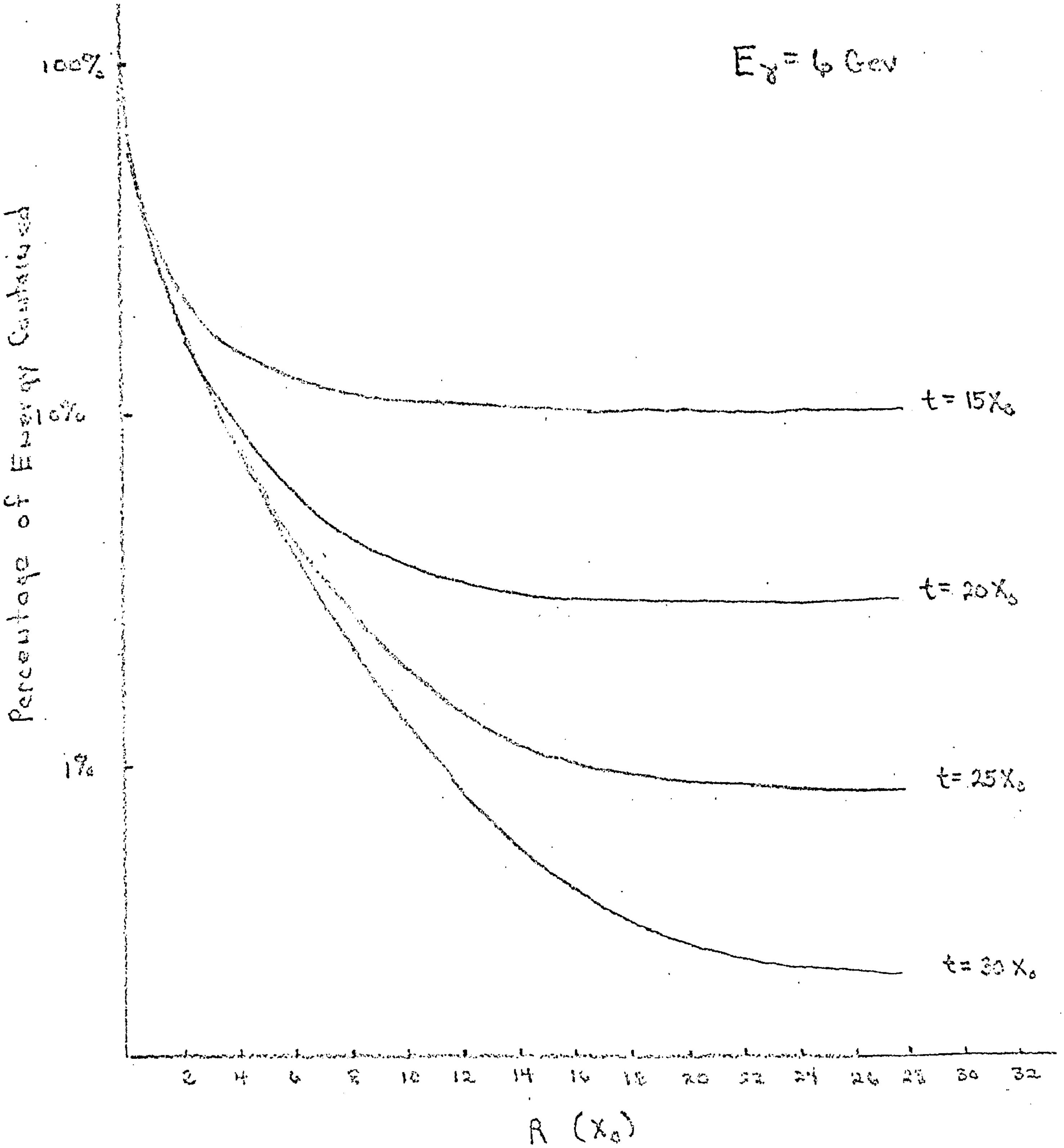
SUBJECT Shower Development	NAME Figure 7		
	DATE		



R = radius of cylinder whose axis is shower axis
t = depth of cylinder
X_0 = radiation length

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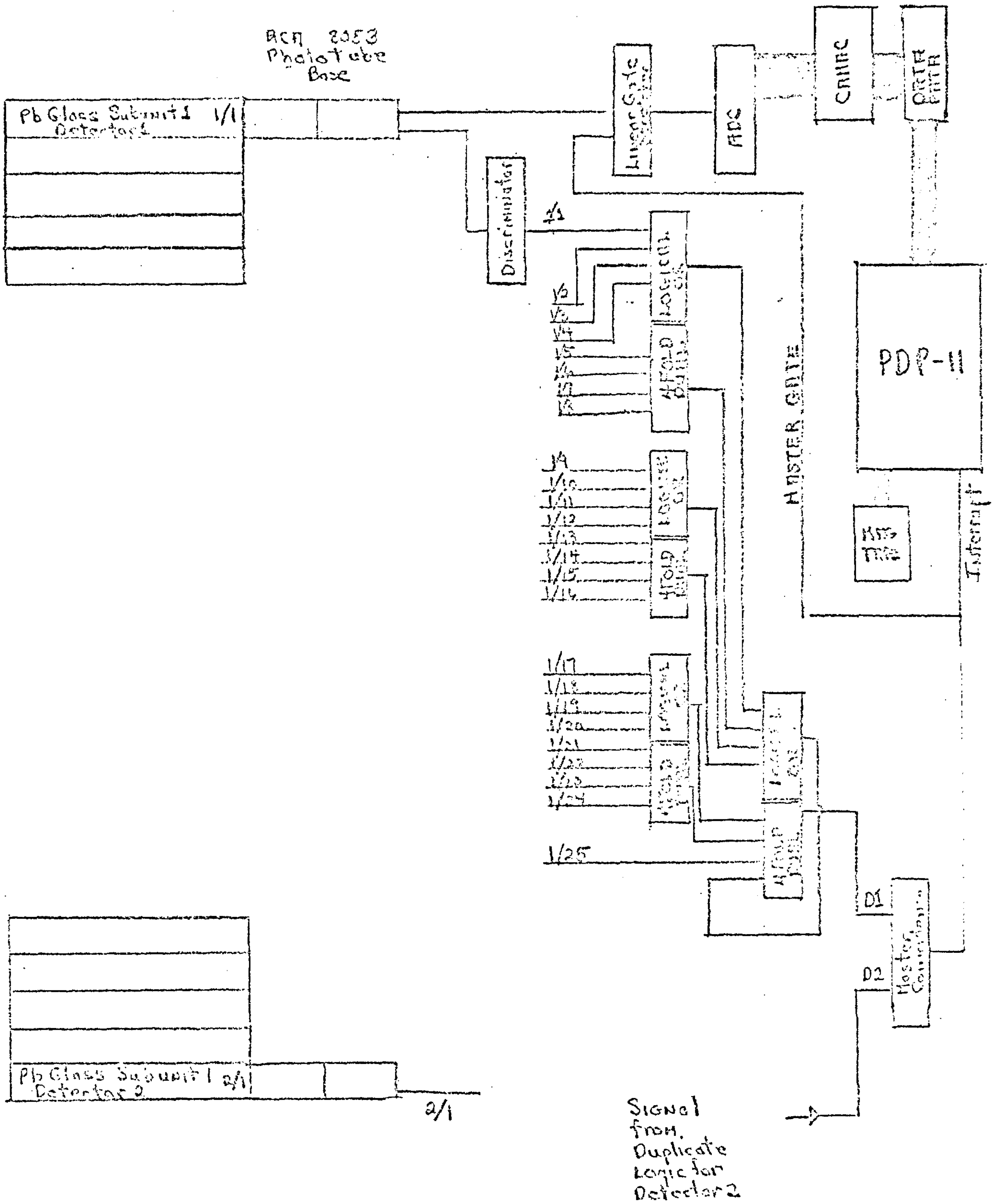
SUBJECT Electronic Logic Schematic	NAME Figure 8		
	DATE		



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SUBJECT Target Holder	NAME Figure 9 DATE